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# SCHOOL OF MINES AND METALLURGY

## UNIVERSITY OF MISSOURI

# BULLETIN

FEBRUARY, 1917

TECHNICAL SERIES

# A PRELIMINARY REPORT ON BLENDED PORTLAND CEMENT

ROLLA, MO.
1917

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UNIVERSITY OF MISSOURI

# A PRELIMINARY REPORT ON BLENDED PORTLAND CEMENT

BY

EDGAR S. McCANDLISS, C. E.,
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ROLLA, MO.
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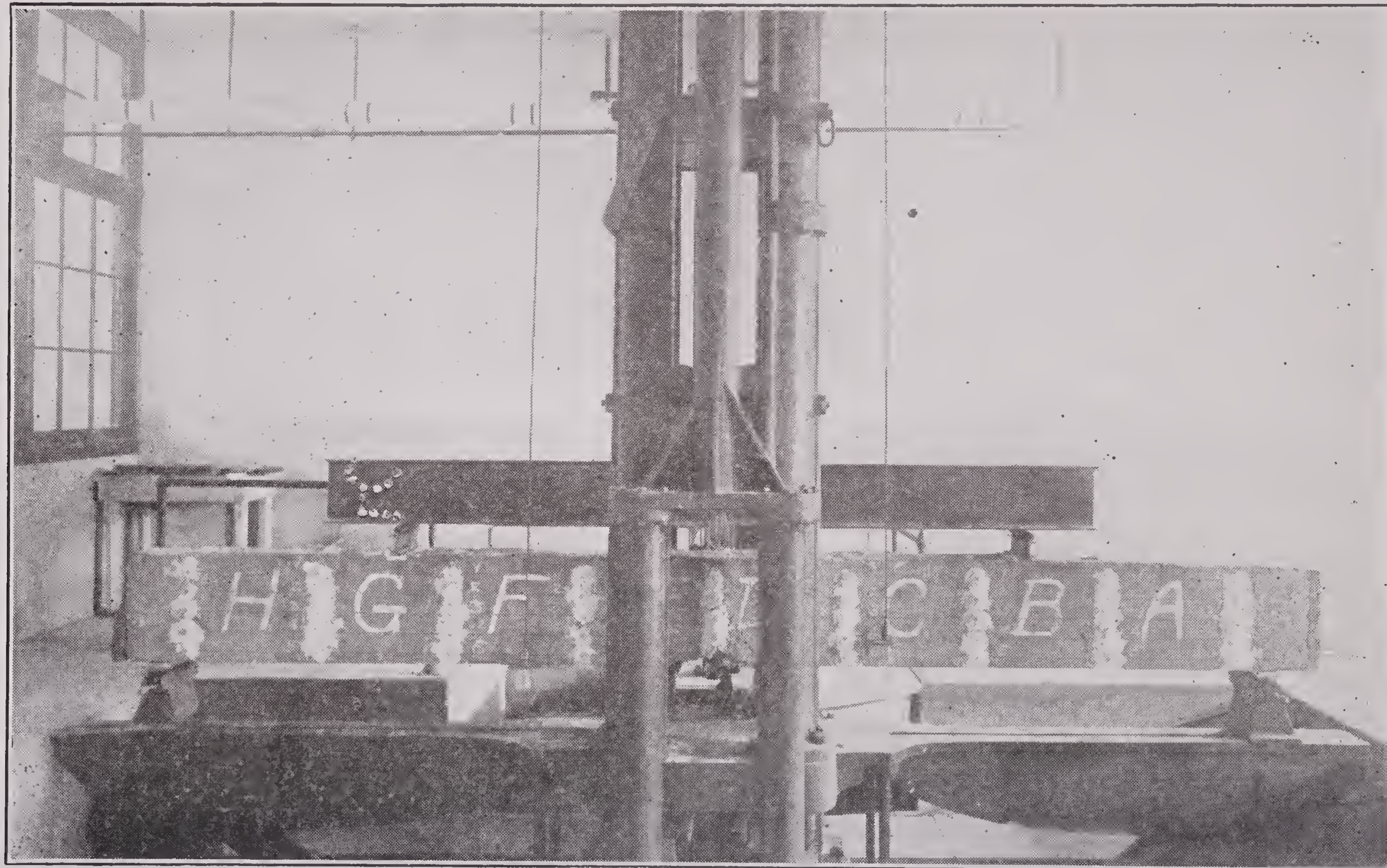


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# BULLETIN

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## School of Mines and Metallurgy

UNIVERSITY OF MISSOURI

*TECHNICAL SERIES*

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## INTRODUCTION

In the fall of 1913 in conjunction with the regular classwork in the cement testing laboratory of the Missouri School of Mines, the author undertook the study of the behavior of sand-blended cements. The results obtained were somewhat surprising, but owing to the limited facilities for carrying on the work, extended investigations were not made at that time. But in 1915 with the installation of the present well equipped laboratory for the testing of materials, it became feasible to carry out experimentation along more extensive lines. One of the problems to receive attention was the continued study of sand-blended cements.

The questions taken up were:

1. Can Portland Cement be blended with sand to produce a sand-blended cement having the same general physical properties as Portland Cement?
2. What amount of sand can be blended with Portland Cement without materially impairing the strength of the blended mixture?
3. In grinding cement clinker, does introducing sand with the clinker in a tube or ball mill facilitate fine grinding?

About three thousand test specimens for tension and compression have been prepared. In order that differences due to personal equation might not affect the results all of these specimens were prepared by the author. It was planned to have the tests extend over a period of two years. The work was started in the fall of 1915 and will be completed in the summer of 1918. This Bulletin gives the tests made on question 1 during the first year. The results of tests on questions 2 and 3 for one year will be completed in October, 1917.

The author takes pleasure in thanking the various cement companies for their co-operation in supplying the cement for these investigations. He is indebted to Mr. H. A. Buehler, Director of the Missouri Bureau of Mines and Geology, for his assistance and advice, and to Messrs. B. L. Ashdown, E. C. Burkhart, C. E. Bardsley, and T. C. Gerber, students in civil engineering at the Missouri School of Mines, for their cheerful assistance.

## CALCAREOUS CEMENTS

The term cement has been applied: To any substance or composition which at one temperature or one degree of moisture is plastic and at another is tenacious; to adhesive mixtures employed to unite objects or parts of objects; to any material, capable of adhering to and uniting into a coherent mass, fragments of a substance not in itself adhesive; to any substance which by hardening causes objects between which it is applied to adhere firmly; to a tenacious infusible substance; to an adhesive or viscous substance; in general to any substance capable of uniting or tending to unite particles of matter into a compact whole. Lutes, glues, solders, gums, putty, mucilage, plasters, limes, hydraulic cements, and similar substances are all comprehended in this definition. Such a definition embraces a large variety of substances which differ one from another in composition, behavior, and importance, and have but few characteristics in common. Because of this, the term cement has become more or less generally restricted to the designation of that group of adhesives which is employed in the construction of engineering works. Cements of this kind bear a chemical relationship to each other, consisting as they do of mixtures which contain compounds of lime as their principal ingredient, in consequence whereof they are termed calcareous cements. Of these the most important by far is Portland Cement.

Portland Cement is a composition, the principal constituents of which are compounds of lime and clay. The abundance of these substances in nature, and the usefulness and cheapness of the cement combine to make it a universal material of construction.

The manufacture of Portland Cement is a highly specialized art, but in general it may be briefly outlined as follows: The clay and the lime are artificially mixed in predetermined proportions depending upon the purity of the materials. This mixture is reduced by grinding to a fine powder and the product roasted at a high temperature. This

roasting causes the powder to undergo chemical and physical changes and the result is a semi-vitrified clinker. This clinker is commonly adjudged to be inert, or devoid of the properties of cements, but when reduced to an extremely fine powder the finest particles possess the property of cements. Hence, in general, Portland Cement may be defined as the material obtained by finely pulverizing the clinker produced by calcining to incipient vitrifaction an intimate artificial admixture of properly proportioned argillaceous and calcareous substances.

Why it is that the particles of the cement clinker are inert when of appreciable size and those of inappreciable size are active, has never been conclusively determined. Nor has the exact size or upper limits in size of the active particles been ascertained. It has, however, been conclusively demonstrated that any particle which will not pass through a standard No. 200 screen has no cementing properties and also that such particles as do pass through this screen are not necessarily active, but that a considerable percentage of it is practically inert. The present standard specifications for fineness of Portland Cement permit of 22% by weight to be retained on a standard No. 200 sieve. Hence it follows that commercial Portland Cement is a material composed of both active and inert particles, the latter being inactive on account of their physical coarseness and their amount being a large percentage of the cement. The desirability of continuing the grinding to reduce this percentage of inactive clinker has been a much discussed problem. But since the apparent increase in strength in the cement is not in proportion to the increased cost of manufacture, and also since the physical behavior of the cement so changes with continued grinding that it sets more rapidly, it appears that the economic limit of grinding cement clinker has been reached. On the other hand, the very fact that these inert particles are present in the cement in large amounts and that they are in reality dormant cement, needing only the energy to break them down to bring out their latent cementing qualities, suggests the presence of a considerable economic waste. If it is necessary to maintain the present graduation in the size of the particles in order to control the behavior of the cement, it is quite possible that some other substance less expensive than cement clinker can be used for the large size particles. In other words, if it is necessary to have these inert particles present in the cement, there are other inert substances in nature, which might be used as a substitute for the inert

clinker particles in case the substitution could be made, thus permitting the further reduction of the clinker into active cement. It is assumed that such a substitution can be accomplished and it is here proposed to study the effect of such a procedure.

The product obtained by mixing Portland Cement with some other finer pulverized substance in a dry condition before being used in mortar or concrete, is commonly termed "blended cement." The substance which is mixed with the Portland Cement is designated the "blending material, or the blend." This latter may be either entirely inactive as a cement or may possess cementing qualities.

The blending of Portland Cement is no innovation as the practice probably made its first appearance in the early nineties. But, owing to the rapid development of the Portland Cement industry with the accompanying reduction in the cost of the product, the practice has been largely discontinued. These cements were manufactured in general by merely mixing the ingredients, Portland Cement and the blend, in a ball or tube mill, no especial effort being made to continue the grinding of the cement. This product was marketed under various trade names such as "silica cement," "sand cement," "tufa cement," etc., the name depending largely upon the nature of the blending material used. While these cements have no importance in present construction as a general proposition, still the economic advantages derived from such methods have not passed into absolute obscurity. Several noteworthy instances might be cited where large constructions have been carried on in which blended cement has been used with satisfaction, whereby considerable economies have been effected. Among the more recent and important of these are the works of the U. S. Reclamation Service and the Los Angeles Aqueduct Commission. In these undertakings the justification for using blended cements has been based largely upon the excessive transportation charges due to the remoteness of the projects from industrial centers. While this condition existed, it is unfortunate that thereby the inference has been given that otherwise blended cements would not have been used, for it is quite possible that in creating this impression an injustice has been done to a worthy practice. The theory has also been advanced that only materials containing active or colloidal silica are suitable for blending Portland Cement. This, of course, excludes quartz sand, and here again it is possible that an erroneous notion is conveyed, for, although it is not pro-

posed to discuss the relative merits of quartz sand as a blend, yet an endeavor will be made to show that it can be used satisfactorily for this purpose.

## PURPOSE

The purpose of this investigation was to study the physical behavior of blended cement of which the blending material was quartz sand. It was proposed to manufacture the blended cements in such a way, as to approach as near as possible the same range in gradation in size of the particles, as occurs in the original Portland Cement. In other words, it was proposed to remove from the Portland Cement a large portion of the inert particles by screening, and for these inert particles to substitute other inert particles of about the same in size. No accurate means were devised for determining the precise amount of the particles removed from the Portland Cement, and therefore several combinations were used which it was thought would give sufficient range to obtain a satisfactory comparison. The end desired was to ascertain whether it is essential in Portland Cement, in order to maintain its present physical characteristics, to have unpulverized clinker for the coarser particles or whether a fine sand would serve the purpose equally well, sand being used because of its having no cementing tendencies and its being abundant in nature.

## SCOPE OF TESTS

The data included in this Bulletin was obtained from testing three commercial Portland Cements and twelve blended cements. For convenience, the tests are grouped in three series, namely, A, B, and C.

Series A comprises the tests of Atlas Portland Cement and four blended cements of this brand. These blended cements are composed (1) of such a portion of the Portland Cement as easily passes No. 200 sieve, and (2) quartz sand, all of which has passed a No. 65 sieve, and about seventeen per cent of which has passed a standard No. 200 sieve. These blended cements, for convenience of identification, are designated $A_{10}$, $A_{20}$, $A_{30}$ and $A_{40}$, the numerals indicating the percentage of weight of sand present in the blended cement.

Series B comprises the tests of Lehigh Portland Cement and four blended cements of this brand. The composition of these blended cements is similar to that of series A and they are designated similarly as $B_{10}$, $B_{20}$, $B_{30}$, and $B_{40}$.

Series C comprises the tests of Red Ring Portland Ce-

ment and four blended cements of this brand. The composition of these blended cements is as before, and they are designated as $C_{10}$, $C_{20}$, $C_{30}$, $C_{40}$.

Thus it is seen that the three series are identical except the Portland Cements used are different. Chemical analyses were made of each of the materials and the usual physical determinations were made of each of the commercial and blended cements. In addition test specimens for neat and mortar tension and compression were made to cover a two years' period of testing. The results of these tests, but only for the period of one year, are given complete in this Bulletin.

## MATERIALS

In selecting the materials for use, an effort was made to choose such brands of Portland Cement as would give some range in the character of the component raw ingredients. The basic composition of the Atlas Portland Cement is Mississippian limestone and Pennsylvanian shale; that of the Lehigh Portland is hard Mitchell (Mississippian) limestone and shale; and of the Red Ring Portland, Missippian limestone, Pennsylvanian shale, together with Loess clay. There is no especial difference in the methods used in manufacturing these cements.

The blending material used was a natural quartz sand from Ottawa, Illinois. It was supplied by the Ottawa Silica Company and is marketed under the trade name of "Banding Sand." This sand is quite fine but well graded and with but slight sifting, as has been noted, was found to conform closely in gradation to that of the coarser particles in the Portland Cement, and was therefore a suitable substitute for them in making the blended cement.

For mortar specimens, standard Ottawa sand was used.

Each of these materials was received at the laboratory in good condition and stored in suitable containers. The respective Portland Cements were each passed through a No. 20 sieve before storing to insure uniformity throughout the samples.

## PROCEDURE

The physical tests made were as follows: (a) Neat tension, (b) mortar tension (c) neat compression, (d) mortar compression, (e) normal consistency, (f) time of setting, (g) constancy of volume (normal and accelerated tests), (h) fineness and sieve analysis and (i) specific gravity. The methods for testing cement recommended by the American

Society of Civil Engineers (See Transactions Vol. 75) were followed but with the following exceptions: A sieve analysis was made of each of the cements. The percentage of water used in making mortar specimens was increased one per cent above the recommended values. Sufficient specimens for neat and mortar tension and compression were made to permit of making tests at intervals up to and including two years, the average of three breaks constituting a test. As has been stated above, the two-year tests have not been made, in consequence the results are complete over only a period of one year.

Compressive test specimens were cylinders two inches in diameter and two inches high. They were made in wooden moulds which had been especially prepared for the purpose. These moulds were twelve inches long, four inches wide, and two inches high, and were made in two sections. The sections were held together with dowels and bolts and were provided with three two-inch holes symmetrically placed on the axis of the block. Poplar wood was used, and the moulds were finished and painted and, as an added precaution against absorption of the water from the specimens, the moulds were greased with hard engine oil each time before being used. The moulds were satisfactory, and good specimens were obtained. No tamping device was used, all moulds being filled by hand.

Compression tests were made with two-screw testing machine of the Riehle type, having a capacity of 50,000 pounds. Each specimen upon being removed from the storage tank was calibrated and weighed to ascertain the relative density. The specimens were at once mounted in the machine on a hemispherical bearing plate and imbedded in plaster of Paris. After centering the specimen in the machine, a light initial load was applied. After the plaster had hardened, continuous load was applied, the moving head of the testing machine travelling at a rate of about .06 inch per minute until failure. The load when first crack appeared in the specimen, as well as the ultimate load, was recorded. These loads were reduced to unit stresses for comparison.

Each of the blended cements was put through the same tests as the Portland Cements except that the chemical analyses and specific gravities were computed and not determined experimentally and no determinations for fineness or sieve analysis were made. In preparing the blended cements each test was prepared separately, only enough of the materials being laid out at a time to make three test

specimens. The coarse particles were removed from the Portland Cements by screening through a standard No. 200 sieve and those of the banding sand by screening through a No. 65 sieve. Enough of each of these materials was then weighed out to produce 500 or 1,000 grams of blended cement in the proportion desired, 500 grams being used in making the test specimens for tension and 1,000 grams the specimens for compression. The sand and the cement were then mixed by passing the mixture successively through a No. 35 screen six times. The resulting blended cement was uniform in color and had every indication of being well combined. It was noted, however, that the materials separated slightly if the containers were dropped lightly upon the table a few times, a fine rim of sand appearing about the base of the cone of the cement. Therefore extreme care was taken not to disturb the blended cements after they were made until they were formed into test specimens.

## RESULTS OF TESTS

The results of the tests for neat and mortar tension and compression are tabulated and appended to this bulletin, but for facilitating the interpretation of these data, curve sheets have been prepared and these follow:

### (A) Neat Cement in Tension.

On curve sheet No. 1 are plotted the results obtained from tension tests of Atlas Portland Cement "A" and the blended cements made from the same. (See Table A, Appendix.) It will be noted from the curves here shown that each of these cements meets the requirements for neat cement in tension of the standard specifications of the American Society for Testing Materials (1916), which are 175: 500 and 600 pounds at twenty-four hours, seven days, and twenty-eight days respectively. In each case the maximum strength is attained within the first twelve weeks. Cement A, the Portland Cement, attains the greatest maximum strength. For comparison of relative strengths, Table 1 has been compiled. It is intended to show in this table the relative strengths of the five cements at the various ages of testing, the values one to five being assigned to the various relative strengths in their order of importance, 1 indicating the cement developing maximum strength and 5 indicating the one developing the minimum strength at the same period.

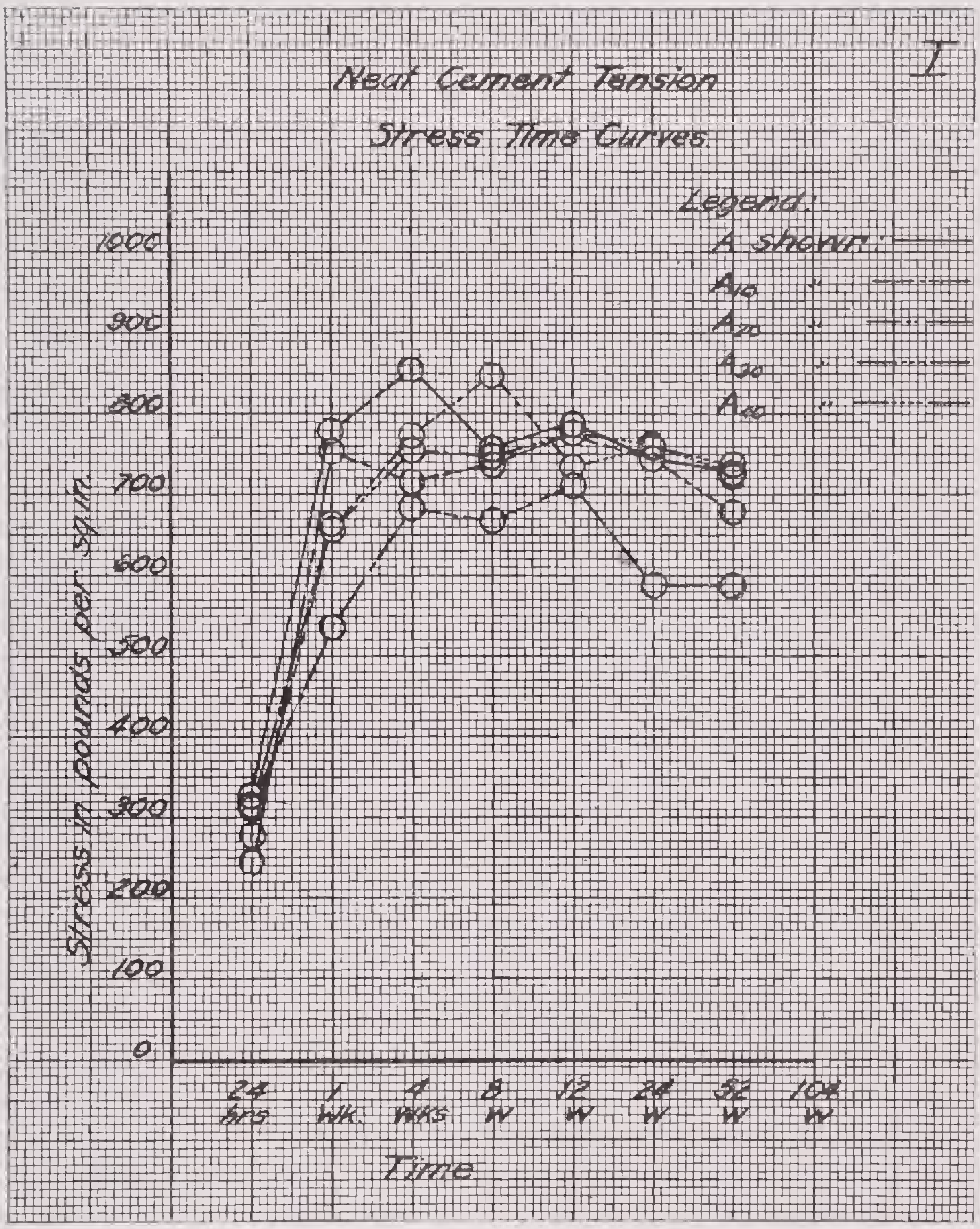

I
Neat Cement Tension
Stress Time Curves
Legend:
A shown:
$A_{10}$ "
$A_{20}$ "
$A_{30}$ "
$A_{40}$ "
Stress in pounds per sq. in.
1000
900
800
700
600
500
400
300
200
100
0
24 hrs
1 wk.
4 wks
8 W
12 W
24 W
52 W
104 W
Time

TABLE I

**RELATIVE STRENGTHS**

| Age of test in weeks | (24 hr.) | 1 | 4 | 8 | 12 | 24 | 52 |
|---|---|---|---|---|---|---|---|
| A | 1 | 1 | 1 | 2 | 1 | 3 | 3 |
| $A_{10}$ | 2 | 5 | 5 | 5 | 5 | 5 | 5 |
| $A_{20}$ | 5 | 2 | 4 | 4 | 3 | 4 | 4 |
| $A_{30}$ | 4 | 3 | 2 | 1 | 4 | 2 | 1 |
| $A_{40}$ | 3 | 4 | 3 | 3 | 2 | 1 | 2 |

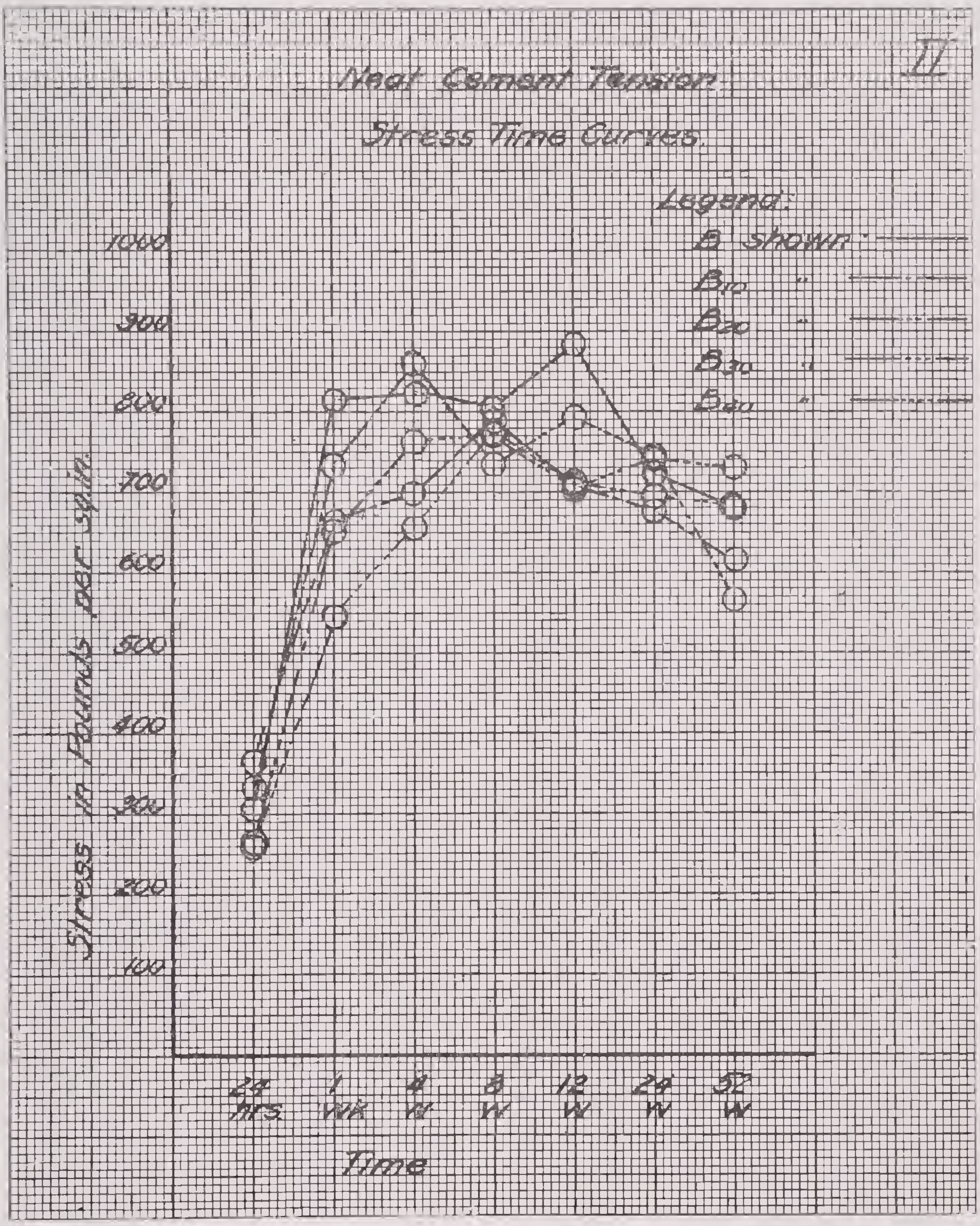
From Table I it is seen that up to and including twelve weeks cement "A" ranges first in point of relative strength. $A_{30}$, second; $A_{40}$, third; $A_{20}$, fourth; and $A_{10}$, fifth. Upon considering the twenty-four and fifty-two week tests, it is seen that $A_{20}$ and $A_{40}$ rank higher than "A", $A_{20}$ and $A_{10}$ retaining fourth and fifth places respectively. This comparison would seem to indicate that within the scope of these tests the blended cements $A_{30}$ and $A_{40}$ are slightly superior to $A_{20}$ and $A_{10}$ in the tensile strength when used neat. From Curve Sheet I blended cement $A_{40}$ seems to develop the most uniform strength, $A_{10}$ the least. From a consideration of early tests, up to twelve weeks, cement "A" seems to be slightly superior to any of the blended cements, but at greater ages the more highly blended cements have equal or superior qualities.

On Curve Sheet II are plotted the results obtained from tests of Lehigh Portland Cement, "B", and the blended cements from the same. (See Table A, Appendix). Each of these cements meets the requirements of the standard specifications of the American Society for Testing Materials (1916). It is to be noted also that in each case the maximum strength is attained within the first twelve weeks, Cement "B" attaining the greatest maximum strength. Table II is similar to Table I.

TABLE II

**RELATIVE STRENGTHS**

| Age of test in weeks | (24 hr.) | 1 | 4 | 8 | 12 | 24 | 52 |
|---|---|---|---|---|---|---|---|
| B | 3 | 1 | 2 | 1 | 1 | 3 | 3 |
| $B_{10}$ | 1 | 3 | 4 | 2 | 4 | 5 | 4 |
| $B_{20}$ | 2 | 2 | 1 | 5 | 2 | 1 | 5 |
| $B_{30}$ | 5 | 4 | 3 | 3 | 3 | 2 | 1 |
| $B_{40}$ | 4 | 5 | 5 | 4 | 5 | 4 | 2 |


IV
Neat Cement Tension.
Stress Time Curves.
Legend:
B shown
B10 "
B20 "
B30 "
B40 "
1000
900
800
700
600
500
400
300
200
100
Stress in Pounds per sq. in.
24 hrs.
1 Wk
4 W
8 W
12 W
24 W
52 W
Time

From Table II Cement B seems to rank first in relative strength up to and including twelve weeks. Over this period of time $B_{20}$ ranks second, $B_{10}$, third; $B_{30}$, fourth; and $B_{40}$, fifth. This relationship is not pronounced, however, there being several conflicts. It is quite apparent, however, that after twelve weeks $B_{30}$ and $B_{40}$ increase in relative importance and are equal or superior to B, while $B_{10}$ and $B_{20}$ make a relatively less favorable showing. From Curve Sheet II it is seen that $B_{30}$ develops the most uniform strength throughout the entire period of testing.

On Curve Sheet III are plotted the results obtained from testing Red Ring Portland Cement "C" and blended cements made from the same, in tension. (See Table A, Appendix). Each of these cements meets the requirements of the standard specifications of the American Society for Testing Materials (1916). In each case the maximum strength was attained in twelve weeks. Cement "C" attains the greatest maximum strength. Table III is similar to Table I.

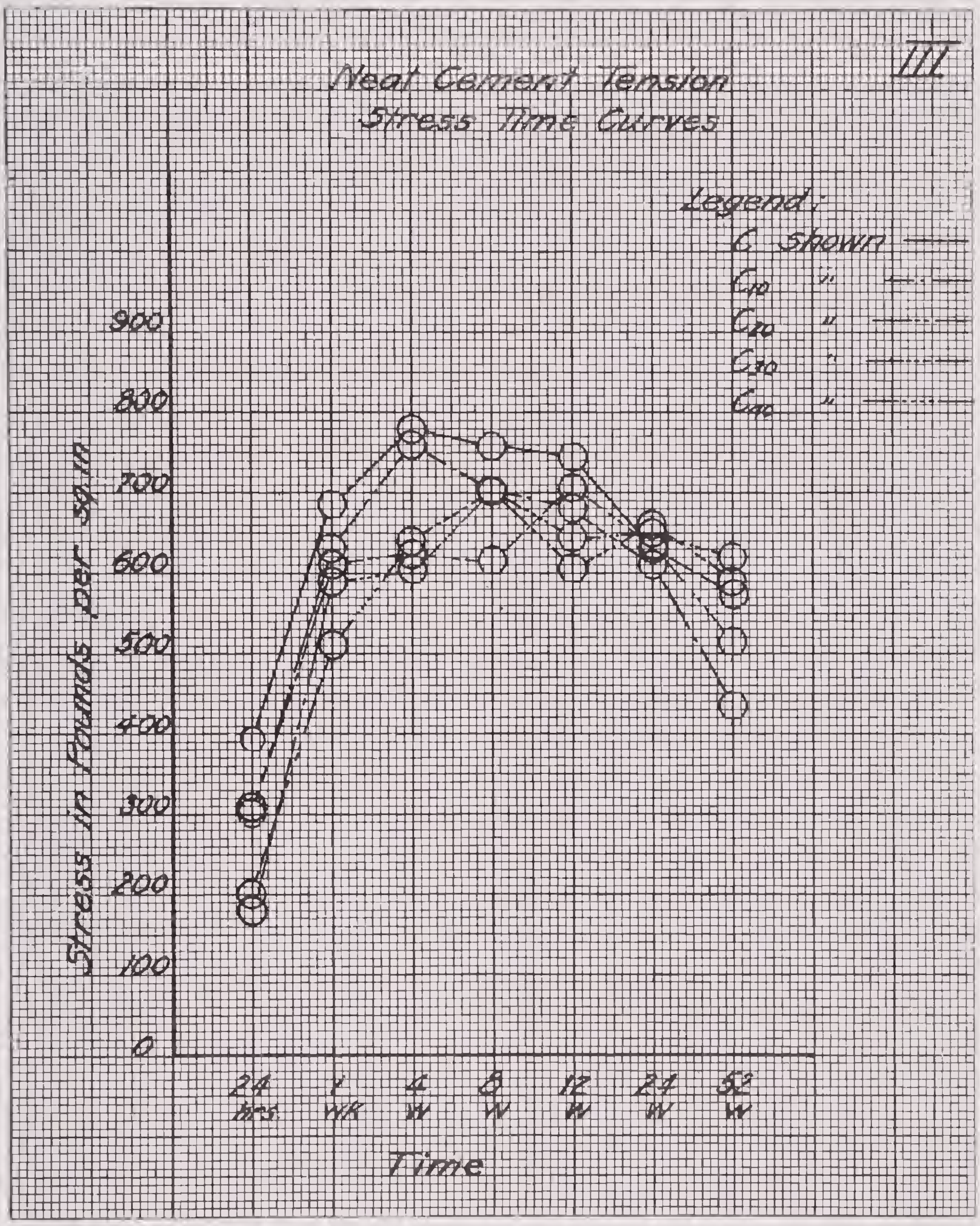
TABLE III

**RELATIVE STRENGTHS**

| Age of test in weeks | (24 hr.) | 1 | 4 | 8 | 12 | 24 | 52 |
|---|---|---|---|---|---|---|---|
| C | 1 | 1 | 1 | 1 | 1 | 3 | 3 |
| $C_{10}$ | 3 | 2 | 2 | 2 | 3 | 5 | 5 |
| $C_{20}$ | 2 | 3 | 4 | 5 | 2 | 4 | 4 |
| $C_{30}$ | 5 | 4 | 5 | 4 | 5 | 1 | 2 |
| $C_{40}$ | 4 | 5 | 3 | 3 | 4 | 2 | 1 |

From Table III it is seen that Cement "C" ranks first in relative strength for the first twelve weeks; $C_{10}$, second; $C_{20}$, third; $C_{40}$, fourth; and $C_{30}$, fifth. This relationship is seen to change, however, as the age increases, $C_{30}$ and $C_{40}$ attaining the greatest relative strengths at the periods of twenty-four and fifty-two weeks, "C" assuming third place; $C_{10}$, fourth; and $C_{20}$, fifth. Blended cement $C_{40}$ is seen to develop the most uniform strength throughout the entire range of testing.

On Curve Sheet IV are plotted the results obtained by averaging the corresponding tests plotted on Curve Sheets I, II, and III. (See Table A "Average of averages," Apdendix). From this Curve Sheet it is seen that in each case the requirements of the standard specifications of the American Society for Testing Materials (1916) are satisfied. The


III
Neat Cement Tension
Stress Time Curves
Legend:
C shown
C10 "
C20 "
C30 "
C40 "
Stress in Pounds per sq. in
900
800
700
600
500
400
300
200
100
0
24 hrs.
1 wk
4 w
8 w
12 w
24 w
52 w
Time

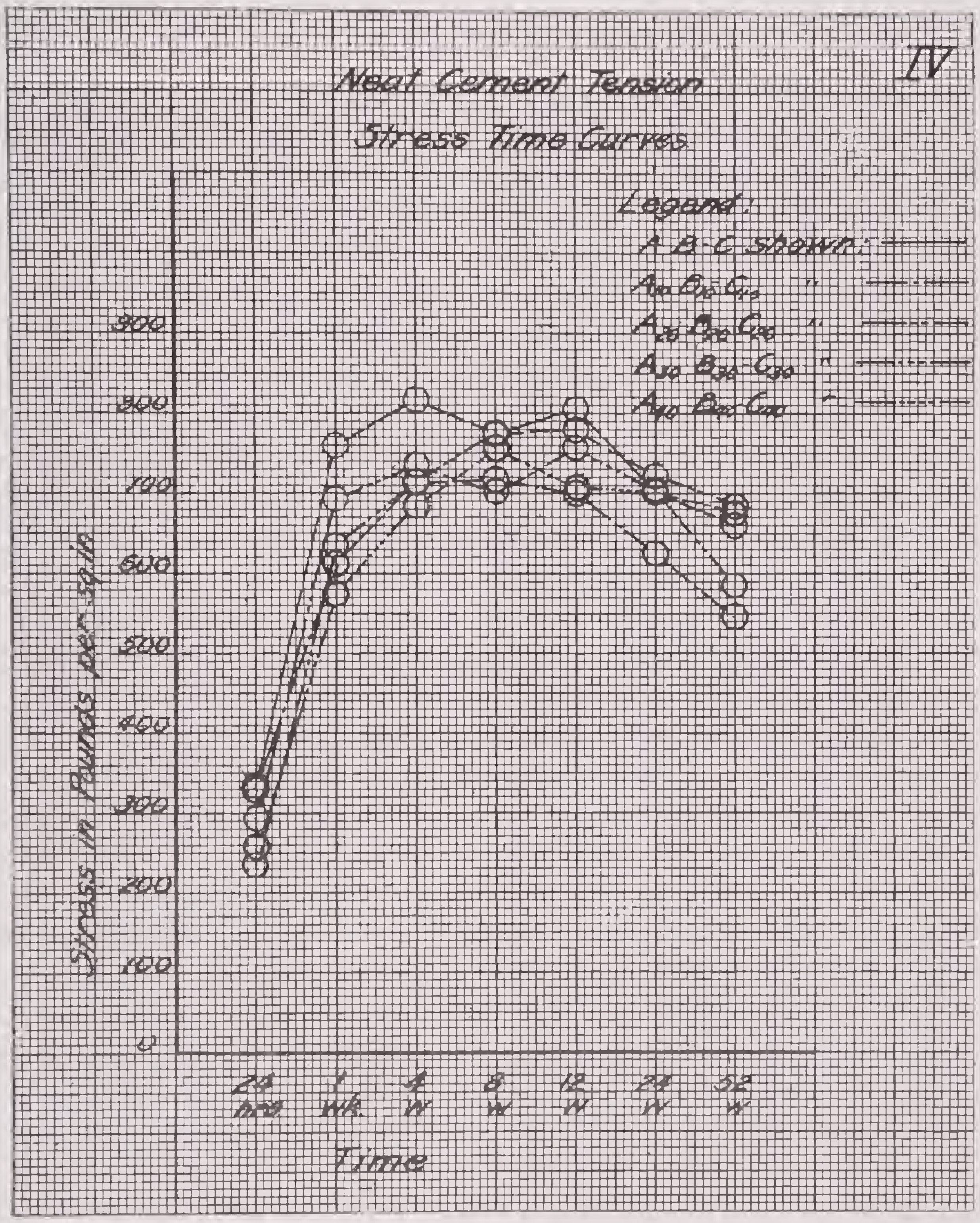
maximum tensile strength is attained in each case in the first twelve weeks. The average of the commercial Portland Cements attains the greatest maximum strength. Table IV is similar to Table I.

TABLE IV

**RELATIVE STRENGTHS**

| Age of test in weeks | (24 hrs.) | 1 | 4 | 8 | 12 | 24 | 52 |
|---|---|---|---|---|---|---|---|
| A-B-C | 1 | 1 | 1 | 1 | 1 | 3 | 3 |
| $A_{10}$ $B_{10}$ $C_{10}$ | 2 | 4 | 3 | 4 | 5 | 5 | 5 |
| $A_{20}$ $B_{20}$ $C_{20}$ | 3 | 2 | 2 | 5 | 3 | 4 | 4 |
| $A_{30}$ $B_{30}$ $C_{30}$ | 5 | 3 | 3 | 2 | 2 | 1 | 1 |
| $A_{40}$ $B_{40}$ $C_{40}$ | 4 | 5 | 5 | 3 | 4 | 2 | 2 |

From Table IV it is seen that the average A, B, C rank first in relative strengths during the first twelve weeks; $A_{20}$, $B_{20}$, $C_{20}$ and $A_{30}$, $B_{30}$, $C_{30}$ second and third respectively; $A_{10}$, $B_{10}$, $C_{10}$ ranking fourth and $A_{40}$, $B_{40}$, $C_{40}$ fifth. With increased ages the relative strengths change, the blended cements $A_{30}$, $B_{30}$, $C_{30}$ assuming first rank; $A_{40}$, $B_{40}$, $C_{40}$, second; A, B, C dropping into third place, $A_{20}$, $B_{20}$, $C_{20}$, fourth; and $A_{10}$, $B_{10}$, $C_{10}$ fifth. It is noted, however, that these changes in relative strengths are not due to increased strengths in the cements with 30 and 40 per cent of blend, but rather to decreasing strengths in the others. The average of the cements with a blend of 45 per cent develops a strength at the age of about four weeks This strength it retains quite consistently as the age increases during the fifty-two weeks of test. The maximum range in variation during this period is about 70 pounds or about ten per cent of the average strength developed. It is intereting to note that the average variation or range in the strengths at the successive periods of testing is about 120 pounds. From a comparison of Curves A, B, and C from Curve Sheets I, II, III, it is seen that the average variation in strength of these commercial cements is about 108 pounds. From this observation, it would seem that had commercial Portland Cements been tested instead of the blended cements and in all other respects had the results been averaged as has been done on Curve Sheet IV, there would have been developed a variation in the strengths practically as great as shown here. In other words there seems to be but little more variation in the strength shown on Curve Sheet IV than might reasonably be expected from that number of commercial Portland Cements, and that in the matter of neat cement in


IV
Neat Cement Tension
Stress Time Curves
Legend:
A-B-C shown:
Stress in Pounds per sq. in
900
800
700
600
500
400
300
200
100
0
24 hrs.
1 wk.
4 W
8 W
12 W
24 W
52 W
Time

tension within the scope of this investigation the blended cements compare favorably with commercial Portland Cements.

**(B) Cement Mortar in Tension.**

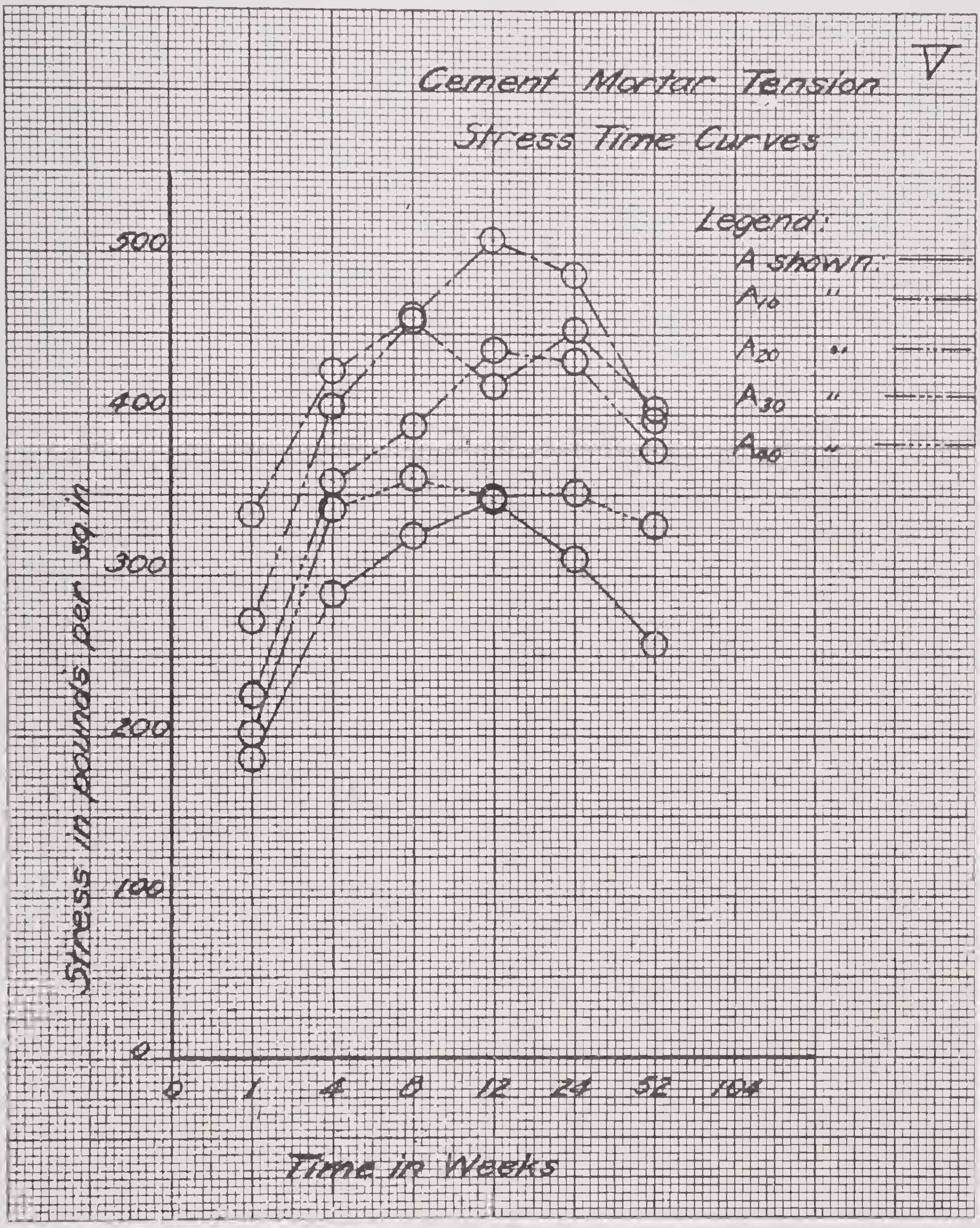
On Curve Sheet V are plotted the results of tests for tension of 1 to 3 mortar specimens of Atlas Portland Cement A and blended cements of the same. (See Table B, Appendix). It will be noted that with the exception of Cement A each of the cements satisfied the requirements of the standard specifications of the American Society for Testing Materials for mortar briquettes in tension, which for 1916 are 200 and 275 pounds per square inch at the ages of seven and twenty-eight days respectively. The specifications for 1917 require 300 pounds per square inch to be developed at the age of twenty-eight days. In each case the maximum strength is attained in the first twelve weeks. Cement A attains the least maximum strength. Cement $A_{40}$ attained a strength of about 350 pounds at four weeks and maintained this strength throughout the remainder of the period. The maximum variation after the first four weeks was about 300 pounds. For the comparison of relative strengths Table V has been prepared. It is similar to Table I.

TABLE V

**RELATIVE STRENGTHS**

| Age of test in weeks | 1 | 4 | 8 | 12 | 24 | 52 |
|---|---|---|---|---|---|---|
| A | 5 | 5 | 5 | 5 | 5 | 5 |
| $A_{10}$ | 1 | 1 | 1 | 1 | 1 | 2 |
| $A_{20}$ | 2 | 2 | 2 | 3 | 2 | 1 |
| $A_{30}$ | 3 | 3 | 3 | 2 | 3 | 3 |
| $A_{40}$ | 4 | 4 | 4 | 4 | 4 | 4 |

From Table V it is seen that in relative strength $A_{10}$ ranks first; $A_{20}$, third; $A_{40}$, fourth, while the commercial Portland Cement "A" ranks last throughout the entire period of testing.


V
Cement Mortar Tension
Stress Time Curves
Legend:
A shown:
A10 "
A20 "
A30 "
A40 "
500
400
300
200
100
0
Stress in pounds per sq. in.
0
1
4
8
12
24
52
104
Time in Weeks

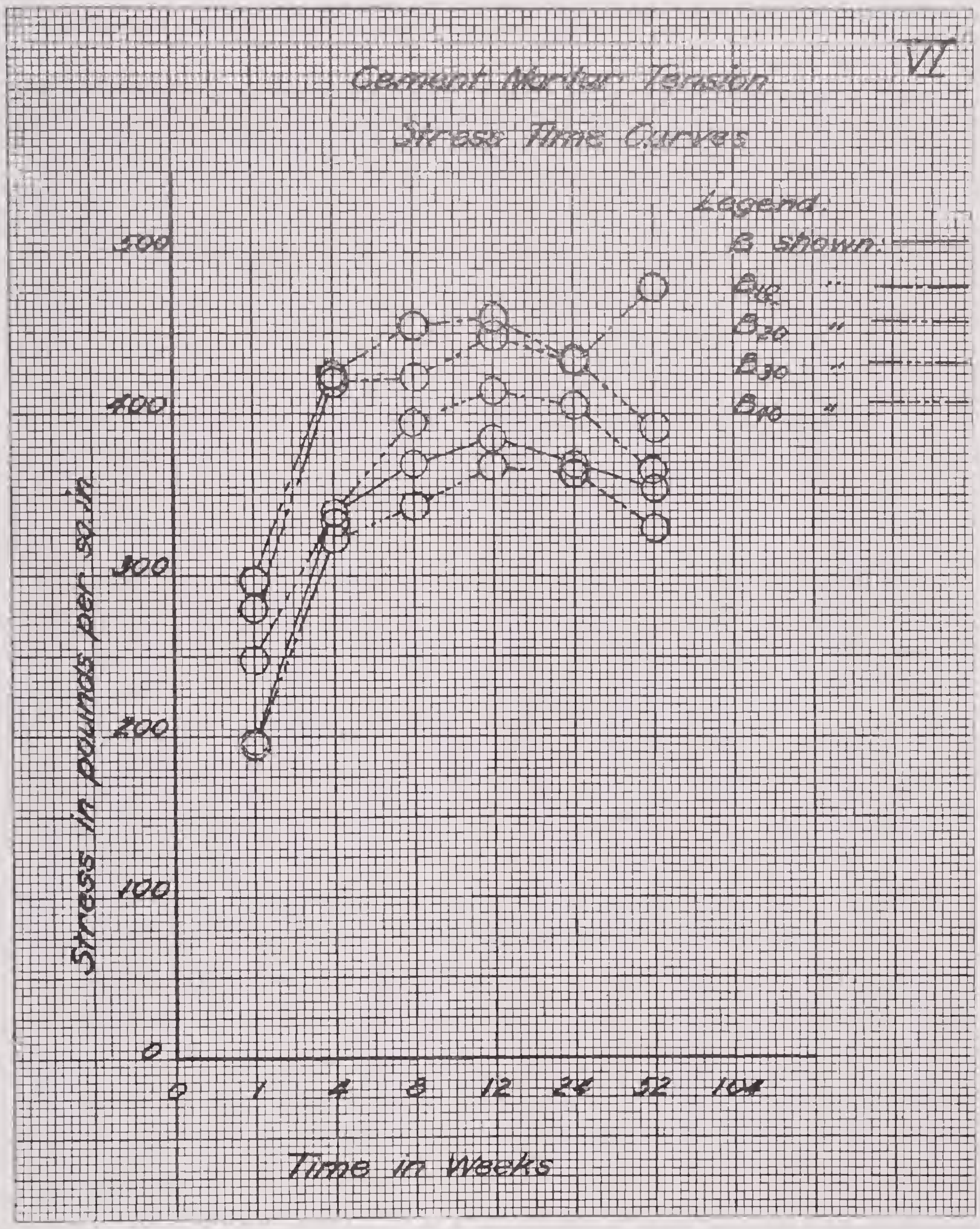
On Curve Sheet VI are plotted the results of tests for tension of 1 to 3 mortar specimens of Lehigh Portland Cement "B", and blended cements of the same. (See Table B, Appendix). It will be noted that each of these cements meets the requirements of the standard specifications of the American Society for Testing Materials (1916 or 1917), for mortar briquettes in tension. Cements B and $B_{40}$ are considered as conforming with the 1917 specifications at an age of one week, with strengths of 197 and 194 pounds per square inch, respectively, in view of their showing at the age of four weeks. Maximum strengths are attained within the first twelve weeks except in the case of $B_{10}$ which shows a maximum strength at fifty-two weeks. Table VI is similar to Table I.

TABLE VI

RELATIVE STRENGTHS

| Age of test in weeks | 1 | 4 | 8 | 12 | 24 | 52 |
|---|---|---|---|---|---|---|
| B | 4 | 4 | 4 | 4 | 4 | 4 |
| $B_{10}$ | 1 | 1 | 1 | 1 | 1 | 1 |
| $B_{20}$ | 2 | 2 | 2 | 2 | 2 | 2 |
| $B_{30}$ | 3 | 3 | 3 | 3 | 3 | 3 |
| $B_{40}$ | 5 | 5 | 5 | 5 | 5 | 5 |

By reference to Table VI it is seen that $B_{10}$ easily ranks first in relative strength throughout the entire period of tension; $B_{20}$, second; $B_{30}$, third; "B", fourth; and $B_{40}$, fifth.


VI
Cement Mortar Tension
Stress Time Curves
Legend.
B shown.
$B_{10}$ "
$B_{20}$ "
$B_{30}$ "
$B_{40}$ "
500
400
300
200
100
0
Stress in pounds per sq.in.
0
1
4
8
12
24
52
104
Time in Weeks

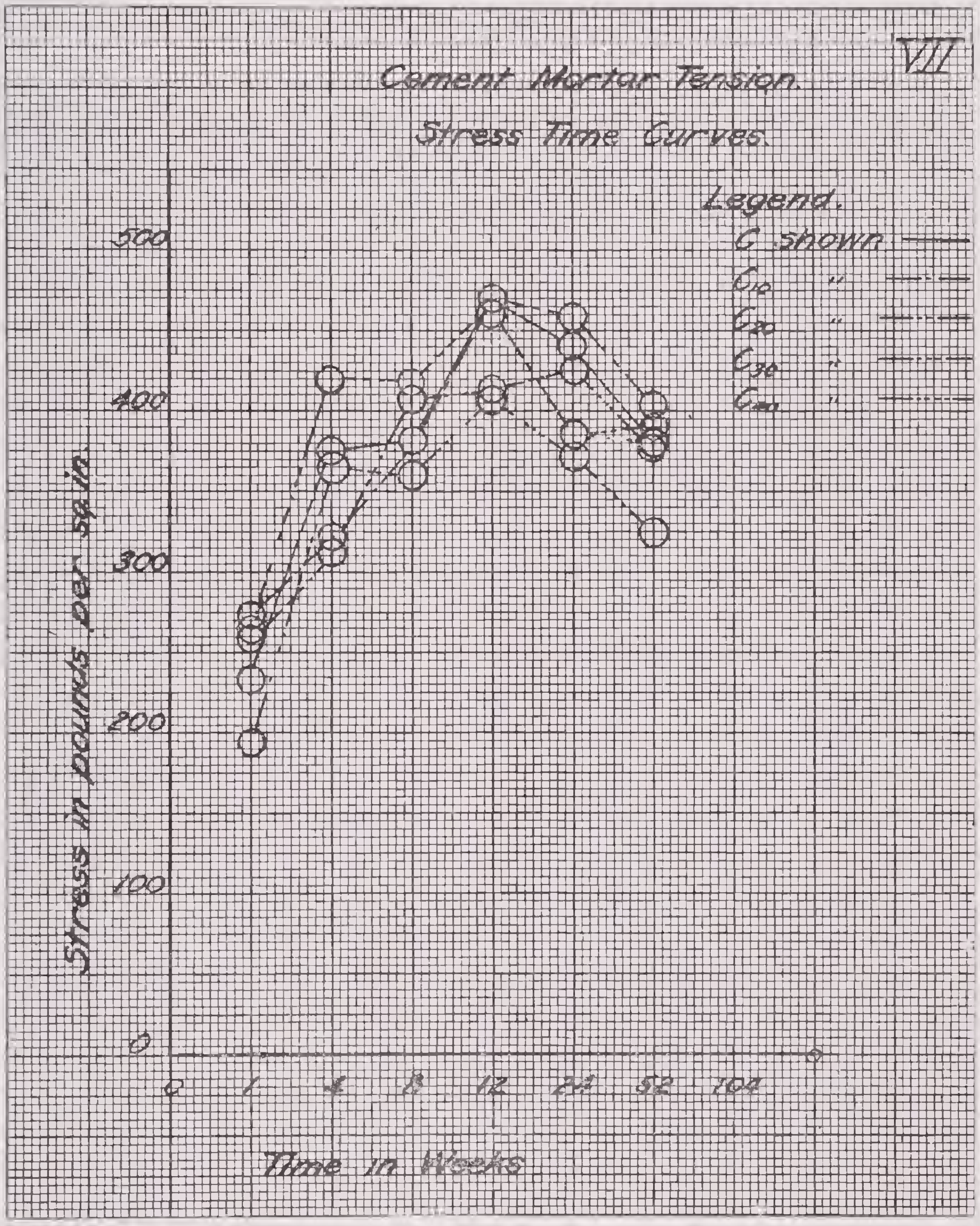
On Curve Sheet VII are plotted the results of the tests for tension of 1 to 3 mortar specimens of Red Ring Portland Cement "C" and blended cements of the same. (See Table B, Appendix). These results seem to be less uniform than those shown on the two previous curve sheets. It will be noted, however, that each of these cements satisfactorily meets the requirements of the standard specifications of the American Society for Testing Materials of mortar briquettes in tension (1916). In each case the maximum strength is attained within the first twelve-week period. Table VII is similar to Table V.

TABLE VII

**RELATIVE STRENGTHS**

| Age of test in weeks | 1 | 4 | 8 | 12 | 24 | 52 |
|---|---|---|---|---|---|---|
| C | 4 | 2 | 3 | 1 | 2 | 3 |
| $C_{10}$ | 1 | 4 | 3 | 1 | 1 | 1 |
| $C_{20}$ | 2 | 1 | 1 | 3 | 4 | 2 |
| $C_{30}$ | 3 | 5 | 2 | 4 | 3 | 4 |
| $C_{40}$ | 5 | 3 | 5 | 5 | 5 | 5 |

From Table VII, while it is more difficult to fix relative compression strength than in some of the previous cases, it is apparent that $C_{40}$ should be classified last or fifth in strength; $C_{30}$ should probably receive fourth place; of the remainder, the classification is more difficult and less well defined, but the classification suggested places $C_{10}$ first, $C_{20}$ second, and C third. It will be noted that this classification corresponds to the relative strengths developed at 1, 12, and 52 weeks, respectively.


VII
Cement Mortar Tension.
Stress Time Curves.
Legend.
C shown
C10 "
C20 "
C30 "
C40 "
500
400
300
200
100
0
Stress in pounds per sq. in.
0 1 4 8 12 24 52 104
Time in Weeks

The values plotted on Curve Sheet VIII represent the results obtained by averaging corresponding values from those plotted on Curve Sheets V, VI, and VII. (See Table B, "Average of averages," Appendix). The results obtained from averaging A, B, and C, the three specimens of commercial cement mortar in tension, should represent approximately the behavior of an average commercial Portland Cement. This curve sheet corresponds with Curve Sheet IV except that the latter is for neat cement in tension. It will be noted here that each of these cements satisfies the requirements of the standard specifications of the American Society for Testing Materials (1916) for cement mortar in tension. Each of the cements attain maximum strength during the first twelve weeks. The differences in strength at any age is not radical, 100 pounds being an approximate average range in strength. For ascertaining relative strengths Table VIII is shown which is similar to Table I.

TABLE VIII

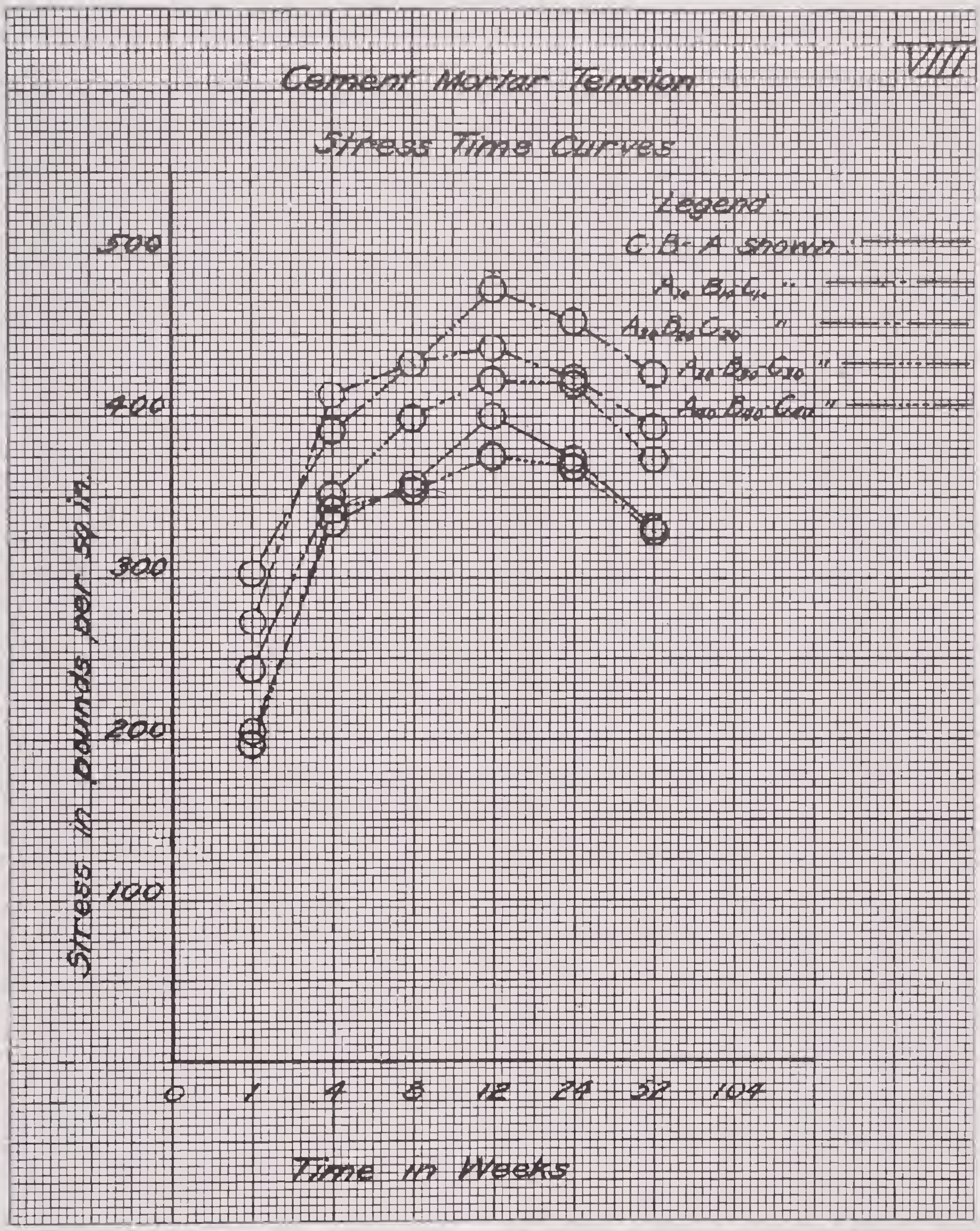
RELATIVE STRENGTHS

| Age of test in weeks | 1 | 4 | 8 | 12 | 24 | 52 |
|---|---|---|---|---|---|---|
| A B C | 4 | 5 | 4 | 4 | 4 | 4 |
| $A_{10}$ $B_{10}$ $C_{10}$ | 1 | 2 | 1 | 1 | 1 | 1 |
| $A_{20}$ $B_{20}$ $C_{20}$ | 2 | 1 | 1 | 2 | 2 | 2 |
| $A_{30}$ $B_{30}$ $C_{30}$ | 3 | 3 | 3 | 3 | 3 | 3 |
| $A_{40}$ $B_{40}$ $C_{40}$ | 5 | 4 | 5 | 5 | 5 | 5 |

Table VIII gives the following classifications: $A_{10}$, $B_{10}$, $C_{10}$ first; $A_{20}$, $B_{20}$, $C_{20}$ second; $A_{30}$, $B_{30}$, $C_{30}$ third; A, B, C fourth; and $A_{40}$, $B_{40}$, $C_{40}$ fifth. by reference to Curve Sheet VIII, it is seen that there is but little difference in strength in A, B, C and $A_{40}$, $B_{40}$, $C_{40}$. In the case of cement mortar in tension, the results of these investigations show that the blended cements are equal or superior to Portland Cement.

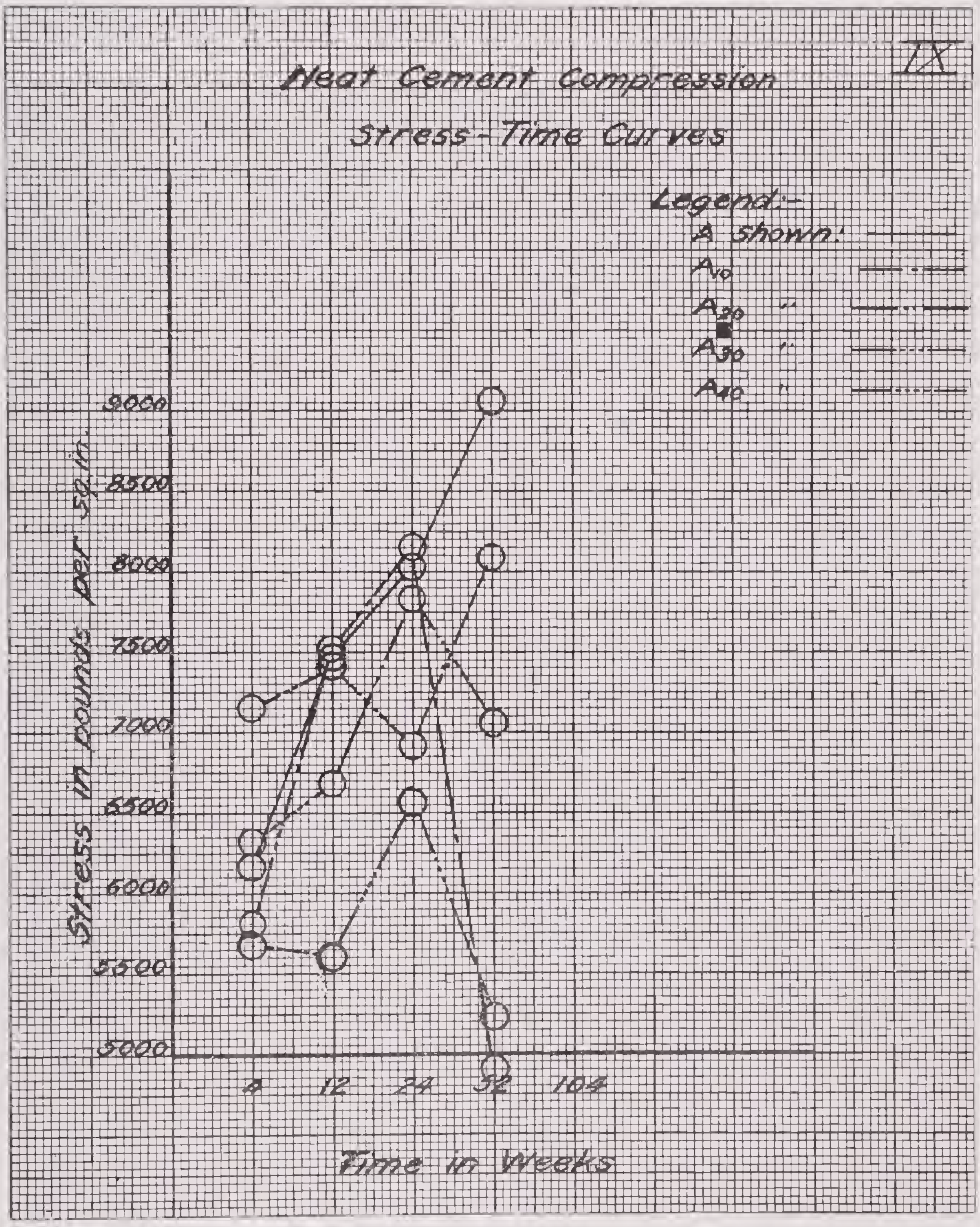
**(C) Neat Cement In Compression.**

The results obtained from each cement in compression cannot be considered satisfactory in all respects. They are apparently inconsistent and contradictory. Tests of a cement made at different time periods seem to follow no general law. In some cases, maximum strengths occur with


VIII
Cement Mortar Tension
Stress Time Curves
Legend.
C-B-A shown
$A_{10}$ $B_{10}$ $C_{10}$ "
$A_{20}$ $B_{20}$ $C_{20}$ "
$A_{30}$ $B_{30}$-$C_{30}$ "
$A_{40}$ $B_{40}$-$C_{40}$ "
500
400
300
200
100
Stress in pounds per sq in.
0 1 4 8 12 24 52 104
Time in Weeks

the oldest tests; in others, at the early test periods. The cause of this eccentricity in results is not apparent. Extreme care was maintained throughout the entire period of experimentation in order to secure uniform conditions, and it is felt that all specimens were treated substantially alike. If it is characteristic of neat cement in compression to show no more uniformity in the results than those here obtained, there seem to be no data available to establish the fact. It is significant, however, that the results obtained from the Portland Cements are no more consistent than those gotten from the blended cements, and in no single instance do the results obtained show uniformity of behavior throughout. The like blended cements of the three commercial Portlands show but slight similarity and the commercial Portlands differ one from the other in behavior. The results obtained are submitted without further apology, but it is hoped that further experimentation will afford a basis for a satisfactory explanation of the behavior of these cements in compression. Attention is called to the fact that this is not a standard test, and in consequence there is no specification to be satisfied, but none of all of these tests, with but a single slight exception, falls below the limit of safety for most large buildings, that is, 5000 pounds per square inch.

On Curve Sheet IX are plotted the results obtained from testing Atlas Portland Cement "A" and blended cements of the same in compression (neat). (See Table "C", Appendix). As has been noted, there seems to be no uniformity in the behavior of the various curves. Cement "A" shows a substantial increase in strength throughout the duration of the test, and it would appear that the maximum strength which this cement may attain has not been reached. It is probable, though, that the strength which is attained at 52 weeks will not be greatly increased at later periods. Cement $A_{10}$ follows closely that of "A" within the first 24 weeks, there being but slight preference between them. The unusual drop experienced in the 52-week test of $A_{10}$ is one of the surprises encountered. A review of the results of this 52-week test shows that they have sufficient uniformity to warrant their acceptance and renders unnecessary the breaking of the two-year specimens at this time for check tests. The two-year tests, however, will be matched with interest. Cement $A_{20}$ develops no unusual characteristics, the average results throughout the entire period being fairly consistent. The same may be observed of $A_{30}$. The most unusual development in the tests of $A_{40}$ seems to be the relatively low strength at 52 weeks. No effort is made at this


IX
Neat Cement Compression
Stress-Time Curves
Legend:-
A shown:
A10
A20 "
A30 "
A40 "
Stress in pounds per sq. in.
9000
8500
8000
7500
7000
6500
6000
5500
5000
4
12
24
52
104
Time in Weeks

time to account for this drop in strength. It is hoped that the strength at two years will tend to offset this apparent inconsistency. Table IX is similar to the previous tables, used in comparing relative strength at the various time-intervals, numerals 1 - 5 being assigned to the highest and lowest strengths.

TABLE IX

**RELATIVE STRENGTHS**

| Age of test in weeks | 4 | 12 | 24 | 52 |
|---|---|---|---|---|
| A | 3 | 2 | 2 | 1 |
| $A_{10}$ | 4 | 1 | 1 | 5 |
| $A_{20}$ | 1 | 3 | 4 | 2 |
| $A_{30}$ | 2 | 4 | 3 | 3 |
| $A_{40}$ | 5 | 5 | 5 | 4 |

Exclusive of the 52-week tests, $A_{10}$ has developed the highest average relative strength; A, second; $A_{20}$, third; $A_{30}$, fourth; and $A_{40}$, fifth, although the first four classifications are not consistently defined. Inclusive of the 52-week tests the relative classification gives Cement "A" first rank; $A_{20}$, second; $A_{10}$, third; $A_{30}$, fourth; and $A_{40}$, fifth.

Curve Sheet X is similar to Curve Sheet IX, except that the results plotted are for Lehigh Portland Cement "B" and blended cements of the same. (See Table C, Appendix). Here again many inconsistencies seem to exist; the tests of Cement "B" show marked variation in strength, it having attained a maximum strength at twelve weeks with an accompanying falling off of about 2500 pounds at the 24-week test-period. $B_{10}$ develops an unusual strength at twelve weeks, but this is not maintained at the later periods of testing. This cement develops a very satisfactory average strength throughout the period of testing. $B_{20}$ develops very satisfactory strengths up to and including 24 weeks; but the 52-week test is unusually low. This 52-week test gave results, however, which are sufficiently uniform in range to warrant their acceptance and therefore no check tests were run. $B_{30}$ is similar to $B_{20}$, the average results being somewhat higher. $B_{40}$ seems to give the most consistent results of any of the cements in this series in point of range in strength developed, although its average strength is the lowest. The average strength of $B_{40}$ is about 6400 pounds per square inch over the entire period of testing. Table X is similar to Table IX.

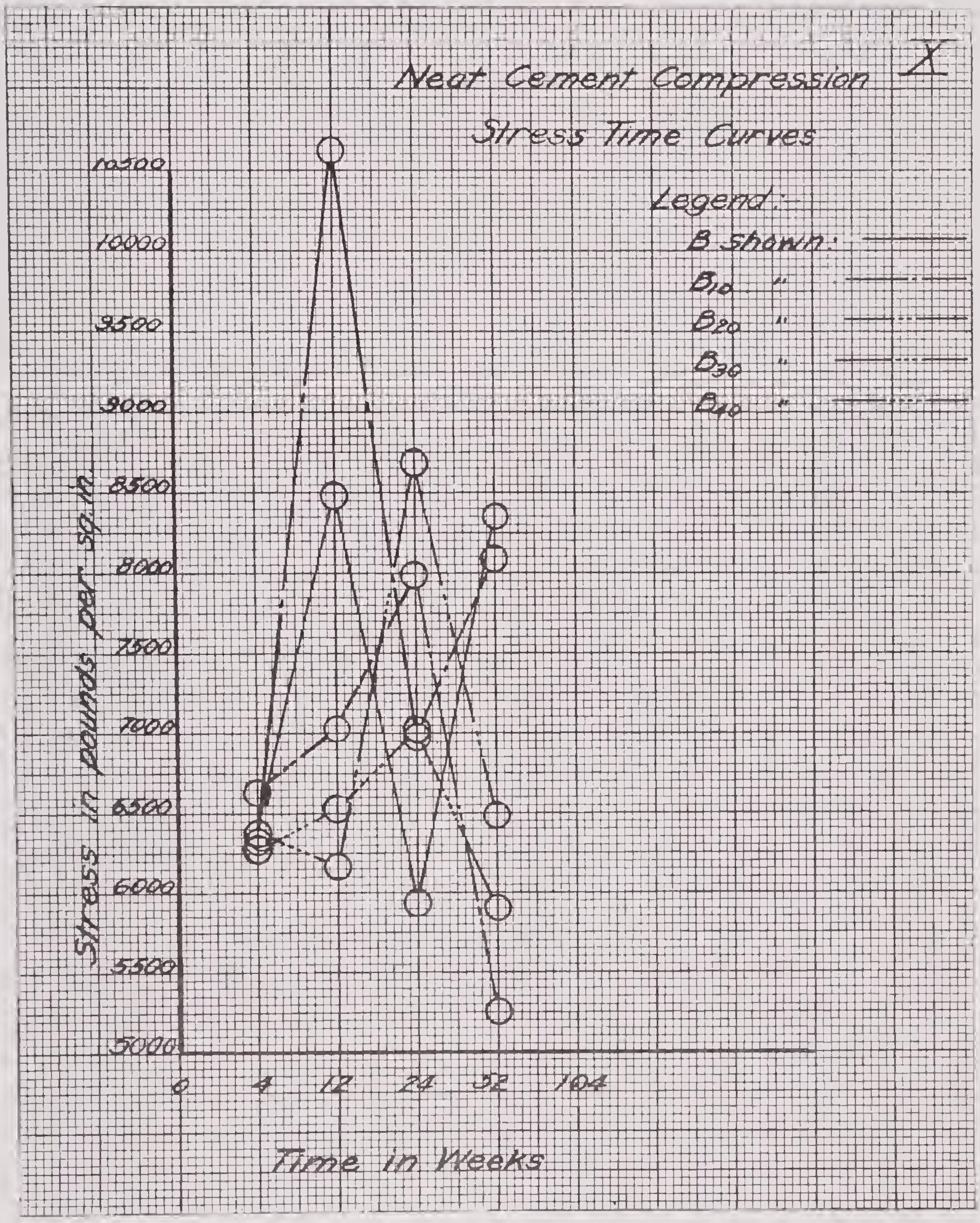

X
Neat Cement Compression
Stress Time Curves
Legend:
B shown:
B10 "
B20 "
B30 "
B40 "
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
Stress in pounds per sq. in.
0
4
12
24
52
104
Time in Weeks

TABLE X

**RELATIVE STRENGTHS**

| Age of test in weeks | 4 | 12 | 24 | 50 |
|---|---|---|---|---|
| B | 3 | 2 | 5 | 1 |
| $B_{10}$ | 2 | 1 | 3 | 2 |
| $B_{20}$ | 1 | 3 | 2 | 5 |
| $B_{30}$ | 3 | 5 | 1 | 3 |
| $B_{40}$ | 5 | 4 | 4 | 4 |

In point of relative strength $B_{10}$ seems to rank first. Since "B" and $B_{20}$ have the same relative strengths during the entire period of testing, there is but little preference between them for second relative rank. $B_{30}$ assumes fourth place, and $B_{40}$, fifth; this distinction, however, is not well definied; in point of excellence there seems to be but little real preference between cements B, $B_{10}$, $B_{20}$, and $B_{30}$. $B_{40}$ is on the average probably somewhat inferior in strength to the others, but this inferiority is not pronounced.

Curve Sheet XI is similar to IX, differing only in the commercial cements used. The results here plotted are those obtained from tests of Red Ring Portland Cement "C" and blended cements of the same. (See Table "C", Appendix). Were it not for the high strength attained at the 24-week period by Cement $C_{20}$, the curves here shown might seem to indicate that the various cements behave in a more or less uniform manner. The maximum strength in each case was developed at 24 weeks, with an accompanying falling off in strength at the test period of 52 weeks.

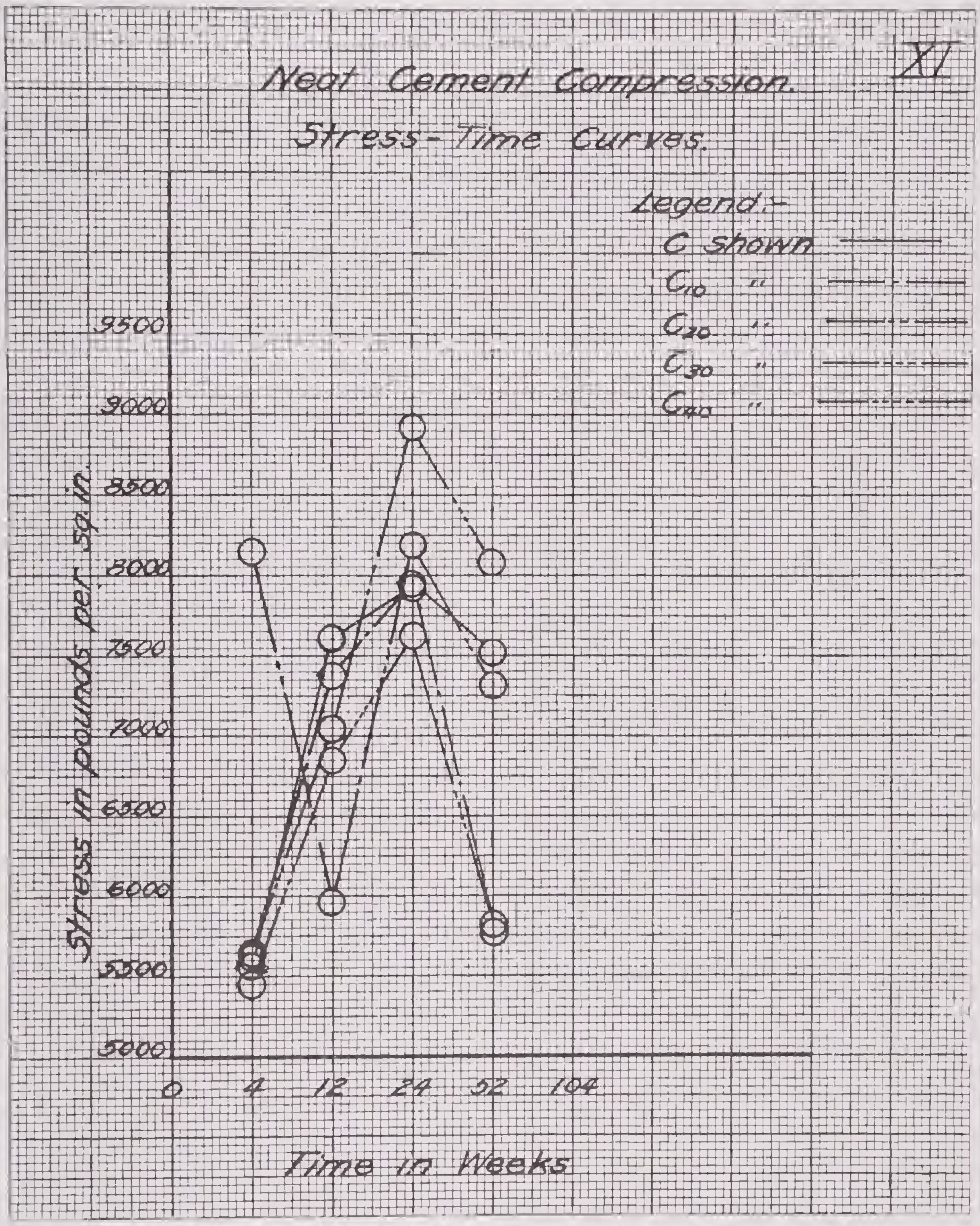
Table XI is similar to Table IX.

TABLE XI

**RELATIVE STRENGTHS**

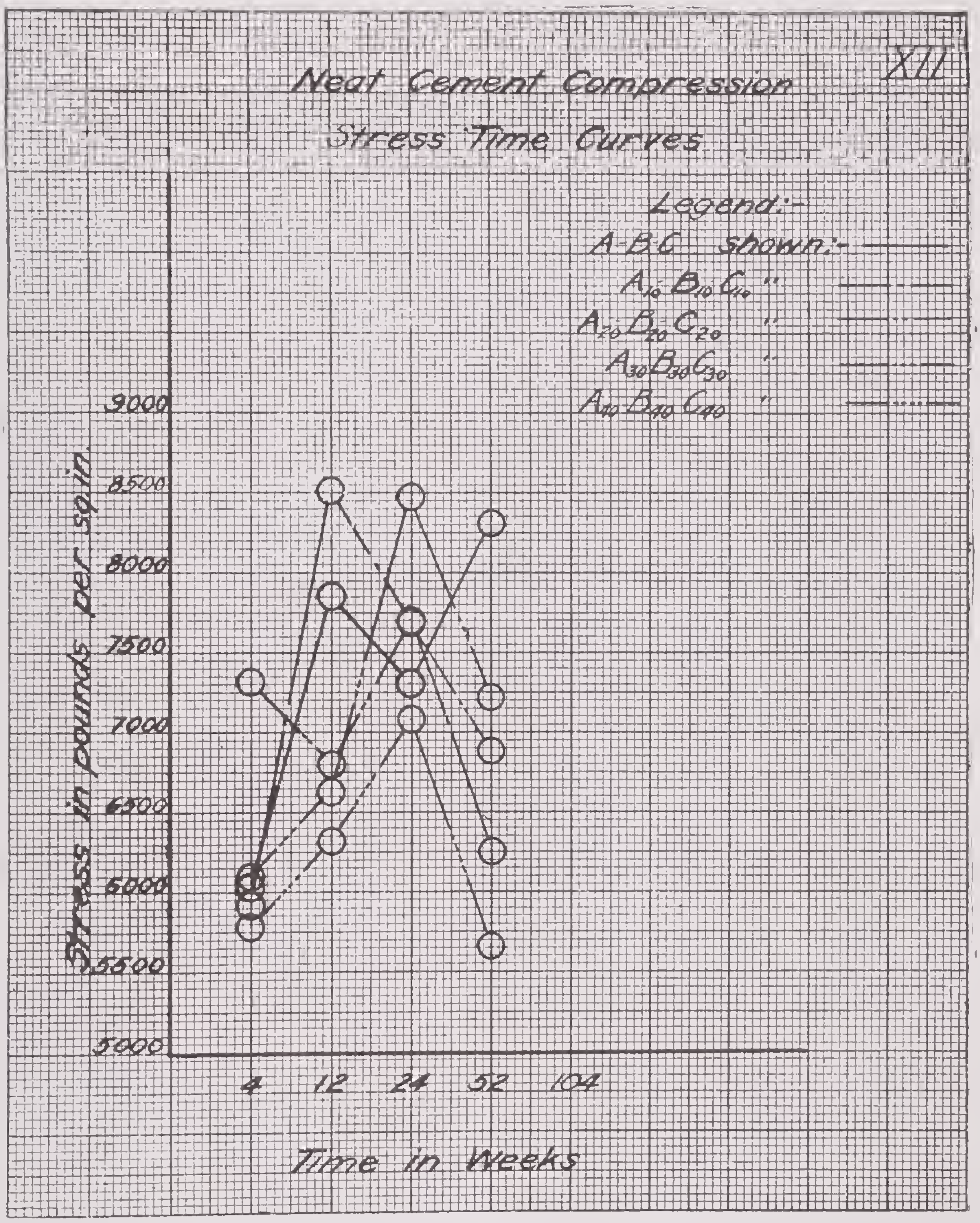
| Age of test in weeks | 4 | 12 | 24 | 52 |
|---|---|---|---|---|
| C | 4 | 1 | 3 | 2 |
| $C_{10}$ | 2 | 2 | 4 | 4 |
| $C_{20}$ | 1 | 5 | 2 | 3 |
| $C_{30}$ | 3 | 3 | 1 | 1 |
| $C_{40}$ | 5 | 4 | 5 | 5 |

The above table, like the two previous ones, shows so much variation that it is problematical whether it has much real significance From this table and in conjunction with


XI
Neat Cement Compression.
Stress-Time Curves.
Legend:-
C shown
C10 "
C20 "
C30 "
C40 "
Stress in pounds per sq. in.
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
0
4
12
24
52
104
Time in Weeks

Curve Sheet XI the following relative classification is made: It is seen that cement $C_{30}$ is far superior to the other tests at the 24 and 52-week periods and is therefore given first relative rank. There is but little choice between C, $C_{10}$, and $C_{20}$, but should a distinction be made it is probable that "C" should receive second place, $C_{20}$, third; and $C_{10}$, fourth. $C_{40}$ ranks fifth in relative importance.

Curve Sheet XII is similar to Curve Sheet VIII in that the results plotted are the average of the three brands of commercial cement and the averages of the corresponding blended cements. (See Table "C" "Average of averages," Appendix). This sheet shows the average results of neat cements in compression and is intended to represent such results as may be expected from an average Portland Cement and blended cements from the same. Here, as with the results which have been averaged, inconsistencies appear, but in less degree than these have been previously noted to occur. From averaging the results from testing commercial cements A, B, and C, it is seen that the strength increases satisfactorily up to the 24-week period, after which there is a falling off in strength. This is not excessive, however, and a complete recovery is noted at the 52-week test-period. In averaging the results of tests of $A_{10}$, $B_{10}$, $C_{10}$ an unusual increase is noted up to the 12-week period of testing. The succeeding tests, however, fall off very markedly, the strength at 52 weeks being considerably lower than that at 24. The averages obtained from $A_{20}$, $B_{20}$, and $C_{20}$ show rather high strengths at four weeks. This characteristic has been noted in each of the separate 20 per cent blended cements. This high strength is not maintained at the twelve-week test-period, although the falling off is not excessive, the unit stress being about 500 pounds; a recovery is noted at 24 weeks with an accompanying falling off at the 52-week test-period. It may be said that the average strength throughout the entire period of testing of this average cement is suite satisfactory and uniform. The results obtained from averaging the $A_{30}$, $B_{30}$, and $C_{30}$ give a curve which is not unusual, there is a consistent increase in strength up to and including 24 weeks with a subsequent reduction in strength at 52 weeks. This reduction is not excessive and a further increase may be expected at the age of two years. The results of the two years tests will be watched with interest. The average results of $A_{40}$, $B_{40}$, $C_{40}$ give a curve which is quite similar to $A_{30}$, $B_{30}$, $C_{30}$, the results obtained at any period of testing, however, being somewhat lower. The relative comparison of strengths is inter-



Neat Cement Compression
Stress Time Curves
XII
Legend:-
A-B-C shown:-
$A_{10}$ $B_{10}$ $C_{10}$ "
$A_{20}$ $B_{20}$ $C_{20}$ "
$A_{30}$ $B_{30}$ $C_{30}$ "
$A_{40}$ $B_{40}$ $C_{40}$ "
9000
8500
8000
7500
7000
6500
6000
5500
5000
Stress in pounds per sq. in.
4
12
24
52
104
Time in Weeks

esting. This is afforded by a study of Table XII, which is similar to the other tables of relative strength previously alluded to.

TABLE XII

**RELATIVE STRENGTHS**

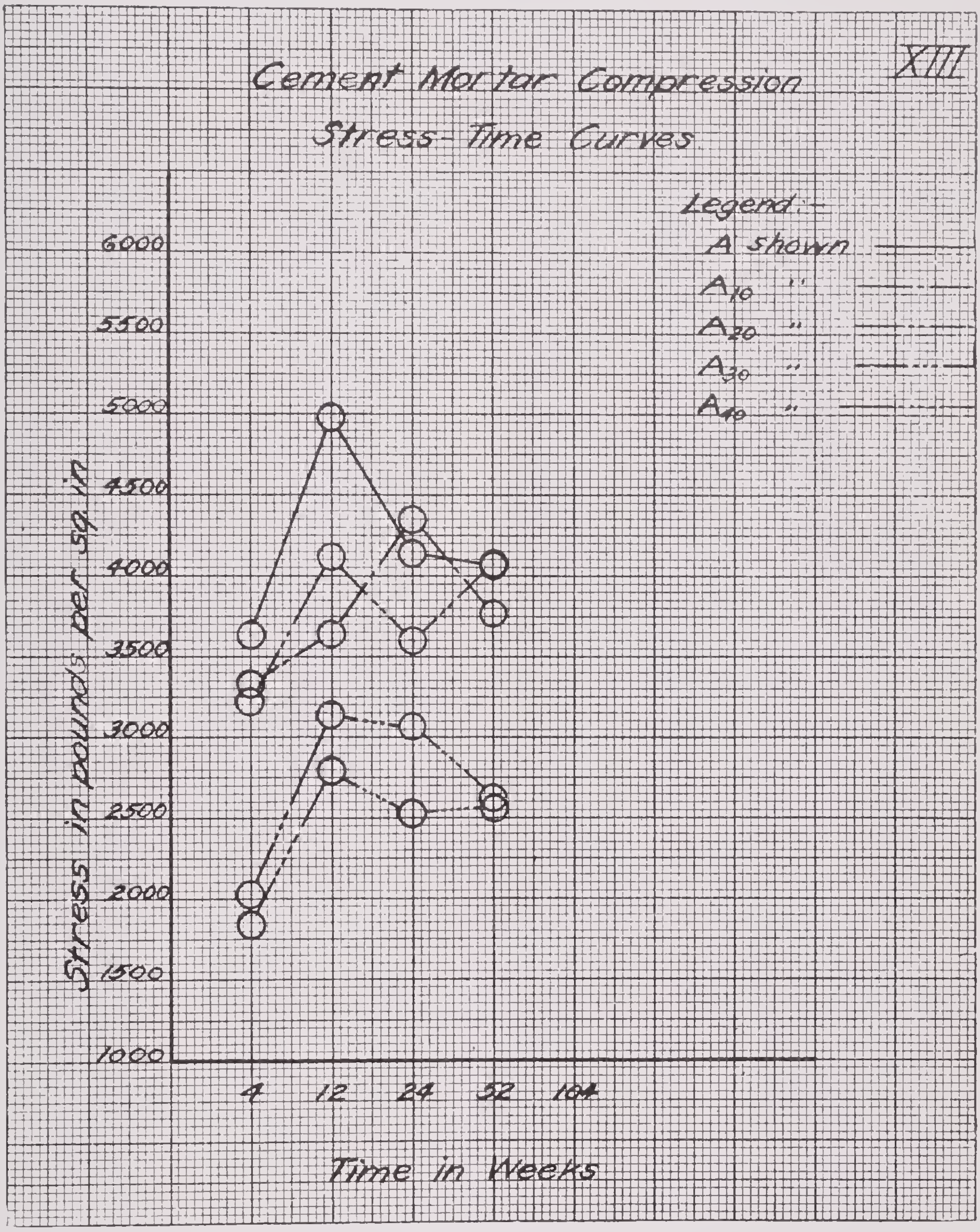
| Age of test in weeks | 4 | 12 | 24 | 52 |
|---|---|---|---|---|
| A B C | 3 | 2 | 4 | 1 |
| $A_{10}$ $B_{10}$ $C_{10}$ | 4 | 1 | 2 | 4 |
| $A_{20}$ $B_{20}$ $C_{20}$ | 1 | 3 | 2 | 3 |
| $A_{30}$ $B_{30}$ $C_{30}$ | 2 | 4 | 1 | 2 |
| $A_{40}$ $B_{40}$ $C_{40}$ | 5 | 5 | 5 | 5 |

By reference to the above table and Curve Sheet XII, the following relative comparison is made. In reverse order it is noted that the average of cements $A_{40}$, $B_{40}$, $C_{40}$ is consistently lowest in strength and therefore is classified fifth. Due to the falling off in strength at the 24 and 52-week periods, the average of cements $A_{10}$, $B_{10}$, $C_{10}$ is given fourth rank in relative importance. Of the three remaining averages, there is scarcely sufficient variation in strengths to warrant relative differentiation. The averages of the 30 per cent blended cements show a slight increase over the 20 per cent averages, the falling off in strength at the 12-week period is against the latter, and the greater strength developed in the former at the later periods may warrant the average of $A_{30}$, $B_{30}$, $C_{30}$ being classified ahead of the average of $A_{20}$, $B_{20}$, $C_{20}$. No effort is made to differentiate between the average results of A, B, C, and $A_{30}$, $B_{30}$, $C_{30}$.

It should be noted throughout these tests in compression that while irregularities occur they are not confined to the blended cements. The Portland Cements manifest eccentricities difficult to explain. The results were not all that was expected, but if they have been interpreted aright they indicate that the blended cements compare faborably with the Portland Cements in tests for neat compression.

**(D) Cement Mortar in Compression.**

The American Society for Testing Materials, in the revision of standard specifications and tests for Portland Cement, proposed the addition of a test which has not hitherto been required, namely, a test for compressive strength of Portland Cement mortar. (See proceedings of the American Society for Testing Materials Vol. 16, page 590.) It is


XIII
Cement Mortar Compression
Stress-Time Curves
Legend:-
A shown
A10 "
A20 "
A30 "
A40 "
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
Stress in pounds per sq. in.
4
12
24
52
104
Time in Weeks

proposed that the average strength in pounds per square inch of not less than three standard test pieces composed of one part of cement and three parts of sand, by weight, shall be equal to or greater than 1200 pounds per square inch at the age of seven days and 2000 pounds per square inch at the age of 28 days, the specimens having been stored one day in moist air the remaining time in water. It is proposed that the test pieces be cylinders 2 inches in diameter and 4 inches high. The results herein reported differ from the above suggestions only in the method of manufacture and in the height of cylinders. The specimens used were 2 inches high instead of 4 inches, as recommended. It should be noted that these specimens were prepared before the appearance of the tentative revisions of the American Society for Testing Materials. No tests were made at seven days.

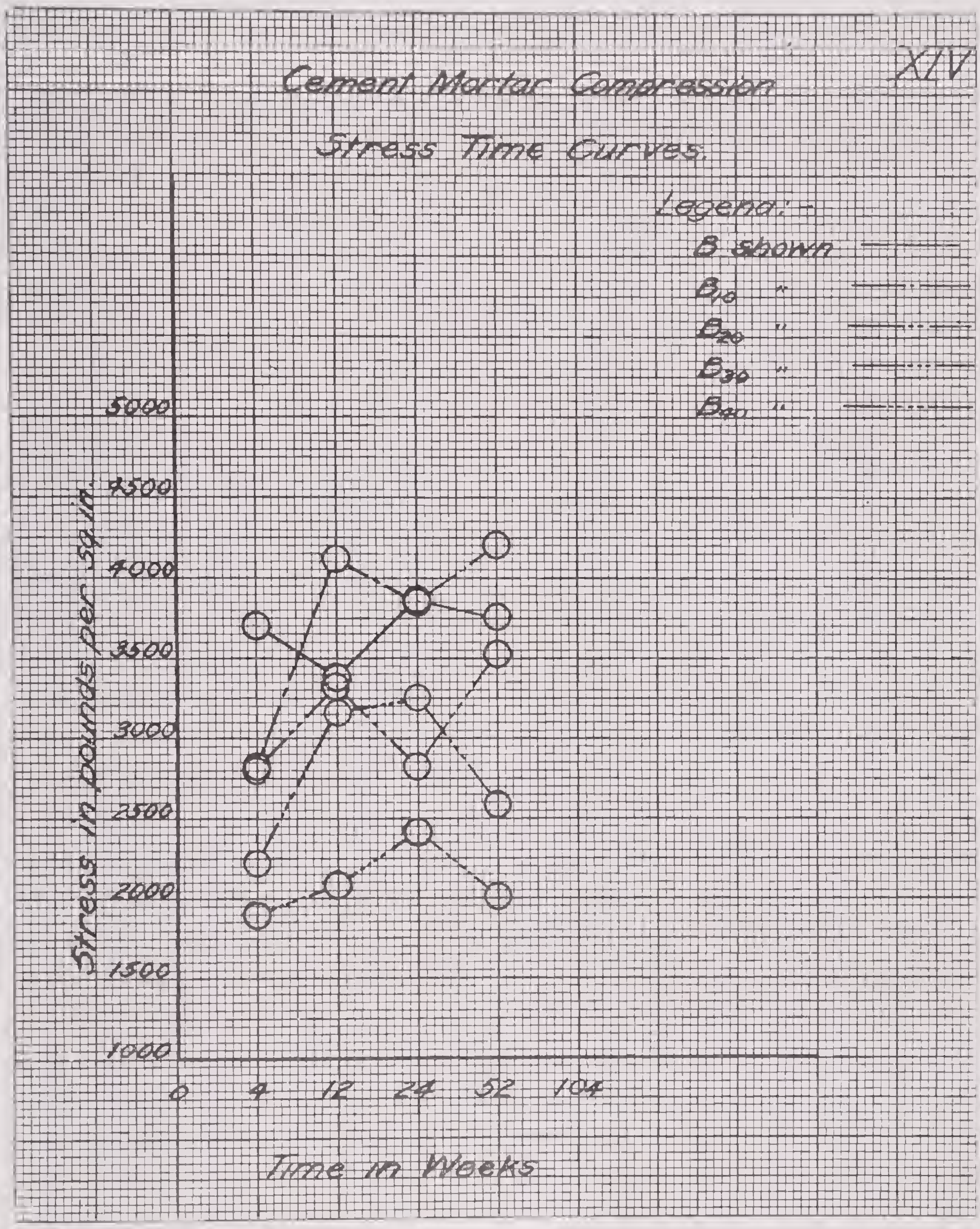
On Curve Sheet XIII are plotted the results obtained from testing mortar speciments of Atlas Portland Cement "A" and blended cements of the same. (See Table "C" Appendix). The strengths obtained increased consistently during the first 12 weeks and with but one exception, ($A_{40}$), atained strengths greater than 2000 pounds per square inch at 28 days (the proposed requirements as noted above. With the exception of $A_{10}$ all cements attain their maximum strength at 12 weeks, $A_{10}$ attaintaining it at 24 weeks. A relative comparison in strength is afforded by Table XIII, which is similar to the previous tables.

TABLE XIII

RELATIVE STRENGTHS

| Age of test in weeks | 4 | 8 | 12 | 24 |
|---|---|---|---|---|
| A | 1 | 1 | 2 | 1 |
| $A_{10}$ | 2 | 3 | 1 | 3 |
| $A_{20}$ | 3 | 2 | 3 | 1 |
| $A_{30}$ | 4 | 4 | 4 | 4 |
| $A_{40}$ | 5 | 5 | 5 | 5 |

Cement "A" seems to have attained the highest relative strength throughout the period of testing although after the 12 week tests this classification is not so pronounced. There is but little choice between $A_{10}$ and $A_{20}$ and these are easily superior to $A_{30}$ and $A_{40}$, the latter receiving fourth and fifth places respectively in relative strengths.


XIV
Cement Mortar Compression
Stress Time Curves.
Legend:-
B shown
$B_{10}$ "
$B_{20}$ "
$B_{30}$ "
$B_{40}$ "
Stress in pounds per sq. in.
5000
4500
4000
3500
3000
2500
2000
1500
1000
0
4
12
24
52
104
Time in Weeks

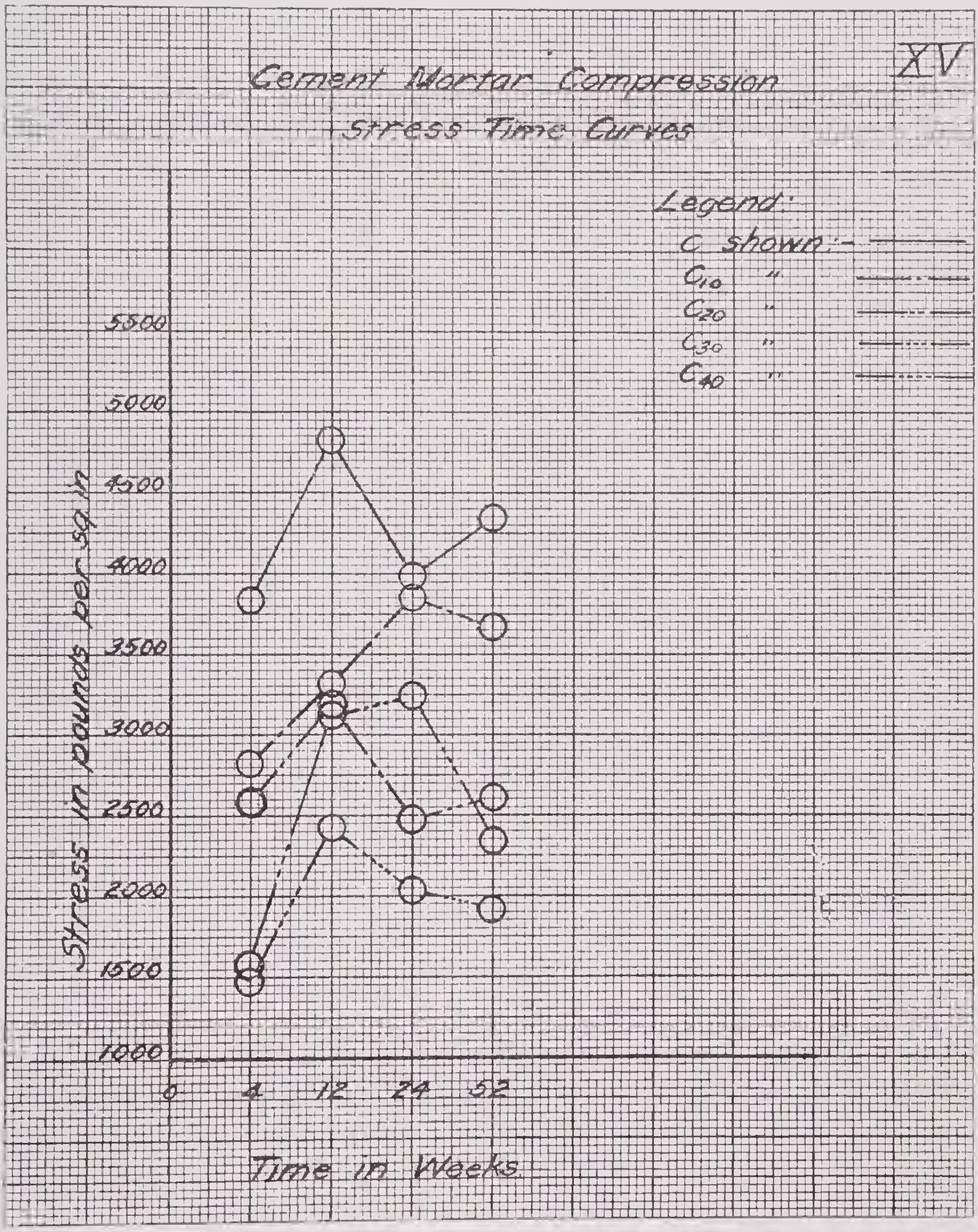
Curve Sheet XIV is similar to Curve Sheet XIII, the results plotted being attained from compressive tests of mortar specimens of Lehigh Portland Cement "B" and blended cements of the same. (See Table "C" Appendix). The results shown, with the exception of Cement $B_{40}$ satisfy the proposed requirements, as has been previously noted, of the American Society for Testing Materials at 28 days. There is not quite the same consistency in results here as is shown on Curve Sheet XIII. Cement "B" shows a loss in strength at 12 weeks. This loss is not excessive and is overcome as shown in the 24 and 52-week tests. Cement $B_{10}$ shows rather more uniform results than does $A_{10}$ and the strengths attained average somewhat higher. The curve $B_{20}$ attains the highest strength at 12 weeks with an accompanying falling off at 24. The maximum strength, however, is attained at 52 weeks, the average strength of this cement throughout the entire period of testing is quite high, being about 3100 pounds per square inch. A consistent increase in strength is shown in the results of $B_{30}$, up to 24 weeks when the maximum strength is attained. The loss at 52 weeks, however, is not excessive nor unusual. Cement $B_{40}$ shows rather lower strengths at all periods of testing than do the other cements, the curve is quite uniform, however, and is probably quite representative of cement mortars having such high percentages of blending material in the cement. Table XIV is similar to Table XIII.

TABLE XIV

**RELATIVE STRENGTHS**

| Age of test in weeks | 4 | 12 | 24 | 52 |
|---|---|---|---|---|
| B | 1 | 2 | 1 | 2 |
| $B_{10}$ | 2 | 1 | 1 | 1 |
| $B_{20}$ | 3 | 3 | 4 | 3 |
| $B_{30}$ | 4 | 4 | 3 | 4 |
| $B_{40}$ | 5 | 5 | 5 | 5 |

A study of the above table in conjunction with Curve Sheet XIV shows but little choice between Cements "B" and $B_{10}$, but a slight preference at the early periods of testing for the former seems to be warranted. At the later periods, however, the preference is reversed. In consequence, the following classification is given: Cement $B_{10}$ ranks first; "B", second; $B_{20}$, third; $B_{30}$, fourth: and $B_{40}$, fifth.


XV
Cement Mortar Compression
Stress Time Curves
Legend:
C shown:-
C10 "
C20 "
C30 "
C40 "
Stress in pounds per sq in
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
0
4
12
24
52
Time in Weeks

Curve Sheet XV shows the plotted results of mortar compression tests of Red Ring Portland Cement "C" and the blended cements of the same. (See Table "C", Appendix).

A wide range in the results obtained in this series of tests characterizes this curve sheet. The values obtained by Cement "C" are uniformly high; those by $C_{40}$ are low; the difference in strength averages about 2300 pounds per square inch throughout the entire period of testing. It is felt that this range is probably excessive. Separately, the curves may be considered quite satisfactory. Curve "C" attaining a maximum strength at twelve weeks with a reduction at 24, followed by a gain at 52 weeks. Curve $C_{10}$ consistently increases in strength to a maximum at 24 weeks with a slight reduction in strength at 52 weeks. Curve $C_{20}$ is similar to Curve "C" in outline; the strengths developed in the former range about two-thirds of those of the latter. The results of testing $C_{30}$ give a curve which is in no sense unusual, a consistent increase in strength being noted up to twenty-four weeks with a slight falling off in the 52-week test. Curve $C_{40}$ is consistently lower in strengths than the other curves. Table XV is similar to the previous tables of relative strengths.

TABLE XV

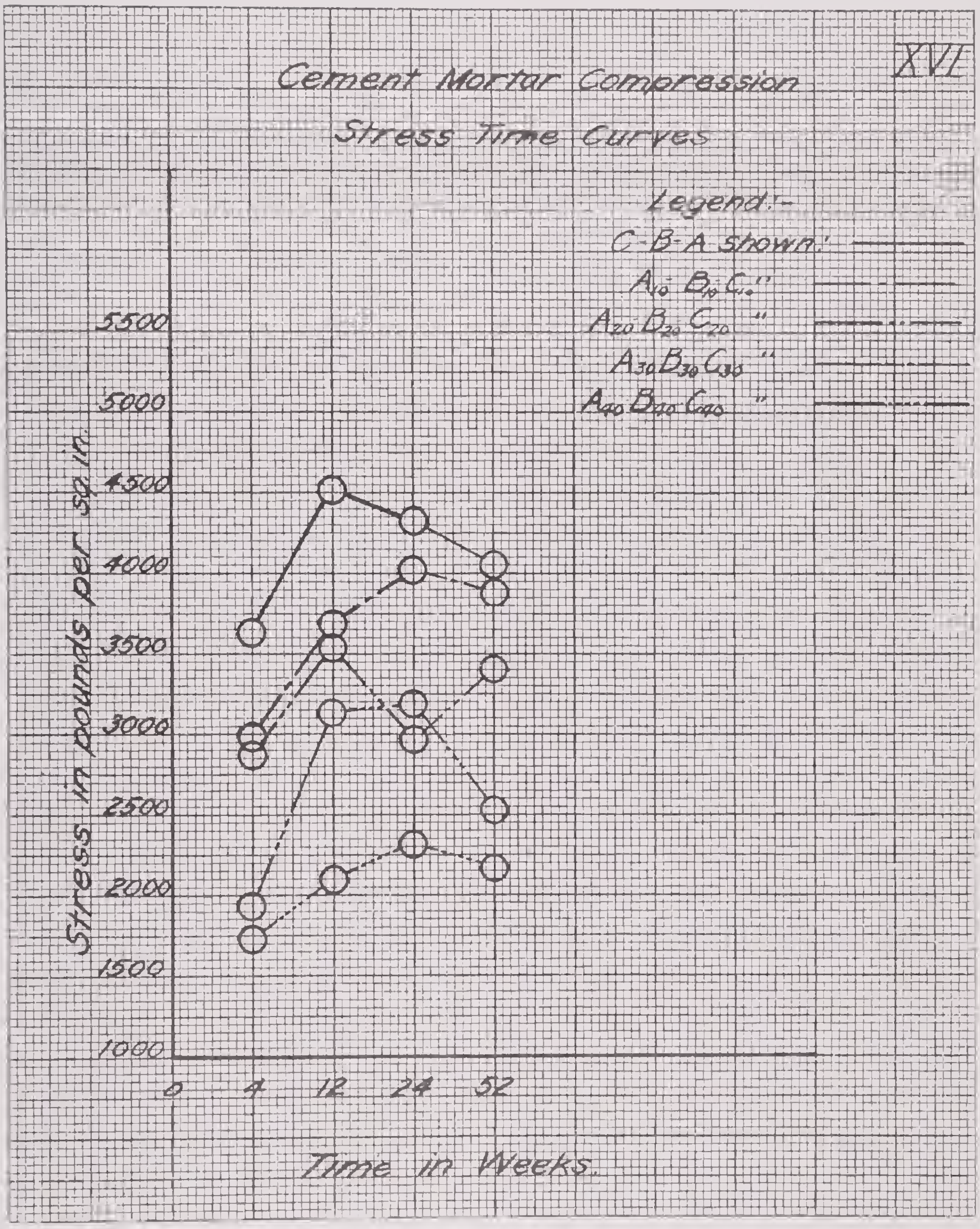
**RELATIVE STRENGTHS**

| Age of test in weeks | 4 | 12 | 24 | 52 |
|---|---|---|---|---|
| C | 1 | 1 | 1 | 1 |
| $C_{10}$ | 2 | 2 | 2 | 2 |
| $C_{20}$ | 3 | 3 | 4 | 3 |
| $C_{30}$ | 4 | 4 | 3 | 4 |
| $C_{40}$ | 5 | 5 | 5 | 5 |

The above table shows an easy comparison of relative strengths, the strengths decreasing as the blending material increases. The mortar from the commercial Portland Cement ranks higher in strength throughout the entire period of testing.

The results obtained from averaging the corresponding tests of the three previous curve sheets are plotted on Curve Sheet XVI. (See Table "C", "Average of averages," Appendix).

It will be noted that the results of tests of mortar specimens from the 40 per cent blended cements are relatively low, falling below the requirements of the proposed specifi-


XVI
Cement Mortar Compression
Stress Time Curves
Legend:-
C-B-A shown:
$A_{10}$ $B_{10}$ $C_{10}$ "
$A_{20}$ $B_{20}$ $C_{20}$ "
$A_{30}$ $B_{30}$ $C_{30}$ "
$A_{40}$ $B_{40}$ $C_{40}$ "
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
Stress in pounds per sq. in.
0
4
12
24
52
Time in Weeks.

cations of the American Society for Testing Material. Results from the tests of the 30 per cent blended cements reveal higher strengths than those of the 40 per cent but in this case the requirements of the proposed specifications of the American Society for Testing Materials are not satisfied, the strengths being about 60 pounds per square inch less than the requirements at 28 days. The results from the 10 and 20 per cent blended cement mortars are well within the specifications referred to and are quite satisfactory in strength throughout the entire period of testing. A relative comparison is made from Curve Sheet XVI. Here is it easily seen that the strengths developed throughout the entire period of testing vary inversely with the amount of blending material used in an almost direct ratio.

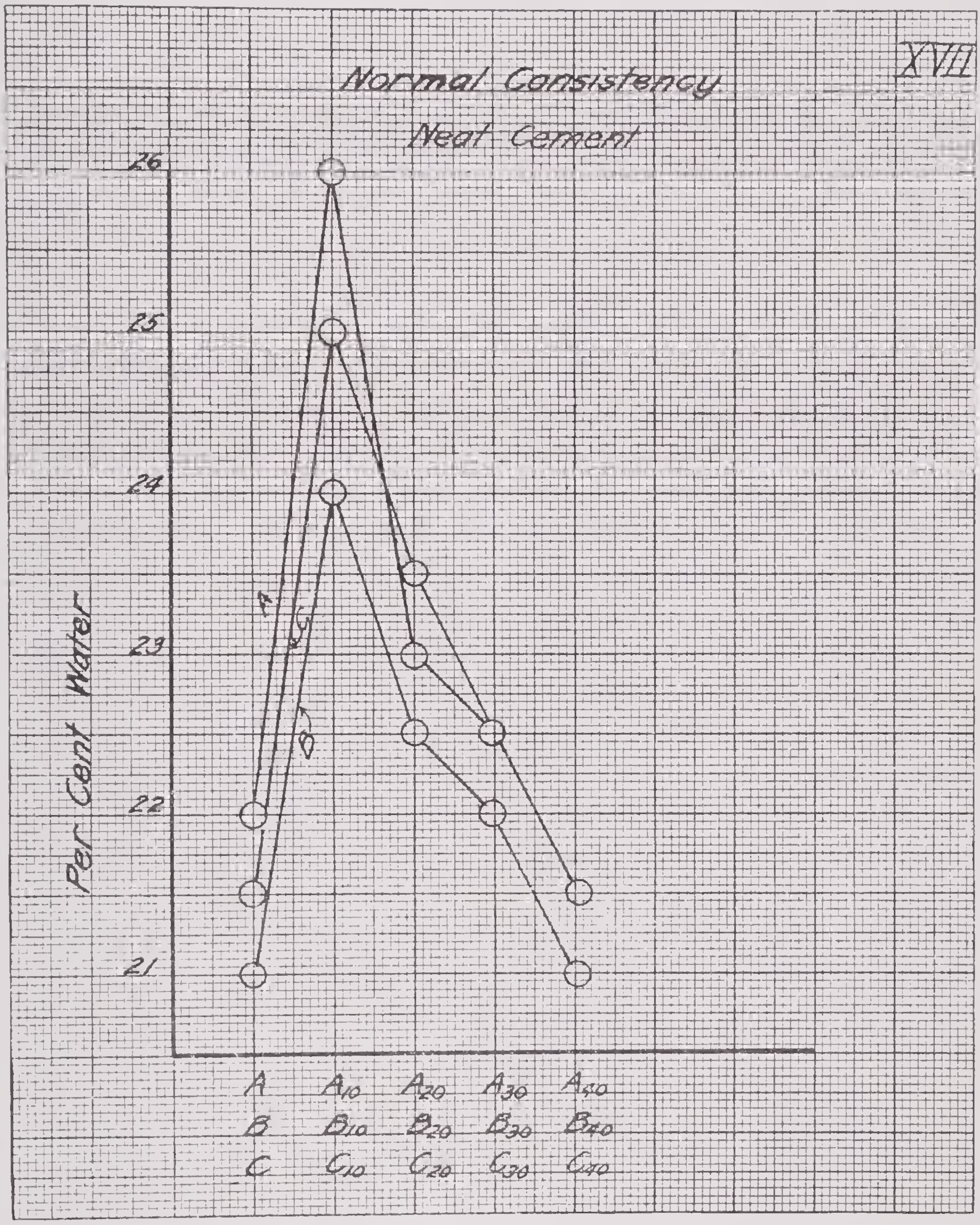
**(E) Normal Consistency.**

The amount of water required to bring the various cement pastes to normal consistency is plotted on Curve Sheet XVII. (See Table D, Appendix). As would be expected, the amount of water increases rapidly from that required for Portland Cement to that required for the 10 per cent blended cement. For, as has been previously stated, the latter carries a higher percentage of the extremely fine Portland Cement than does the former, and in consequence should demand more water if the same degree of hydration is to take place. As the percentage of the blending material increases, the amount of water required should decrease and this assumption is clearly shown to be correct by the accompanying curve sheet.

It was assumed in preparing the blended cements that about 30 per cent of the Portland Cement was removed, that which was retained on a No. 200 sieve being at least that amount. The sifting was not continued to the extent that would be required in a test for fineness. It is not unusual, then, that the 30 per cent blended cement requires approximately the same amount of water for normal consistency as the Portland Cement. As the percentage of water required for normal consistency for mortar specimens was obtained from the standard conversion tables of the specifications of the United States Government for Portland Cement mortar, the characteristics noted above apply also to mortar as well as to cement paste.

**(F) Time of Setting.**

The time required to produce initial and final setting was determined with the Vicat apparatus, and is shown plotted on Curve Sheets XVIII and XIX, respectively. It is tabulated in Table D of appendix. It is significant that


XVII
Normal Consistency
Neat Cement
26
25
24
23
22
21
Per Cent Water
A
C
B
A A10 A20 A30 A40
B B10 B20 B30 B40
C C10 C20 C30 C40

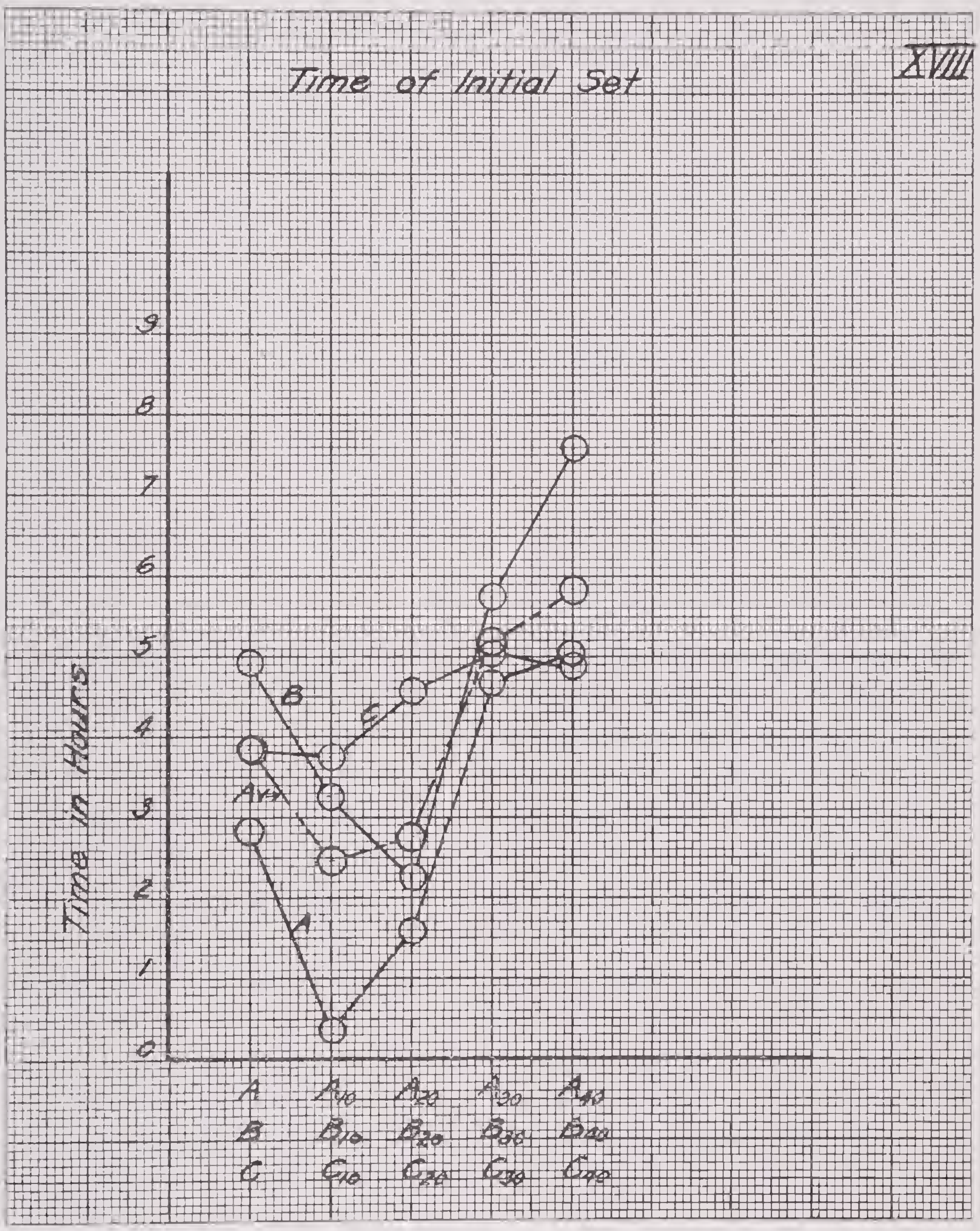
the time of setting is less in a case of the 10 per cent blended cements than with the Portland Cements. As the percentage of blending material increases, the time of setting increases until, when a blending material of between 20 and 30 per cent has been used, the time of setting of the blended cement is equal to that of the Portland Cement. The 40 per cent blended cements are somewhat slower in setting than the Portland Cements.

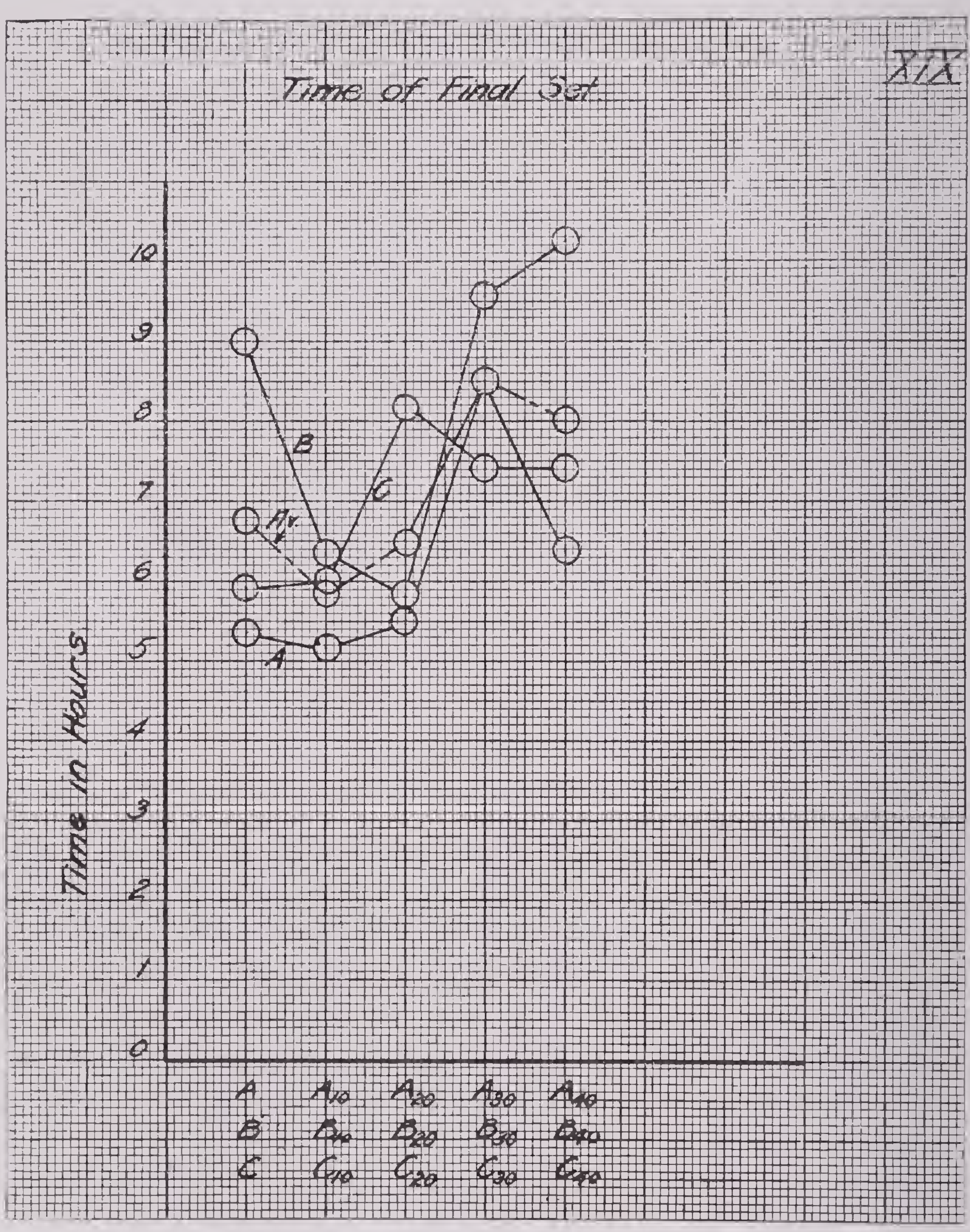
**(G) Constancy of Volume.**

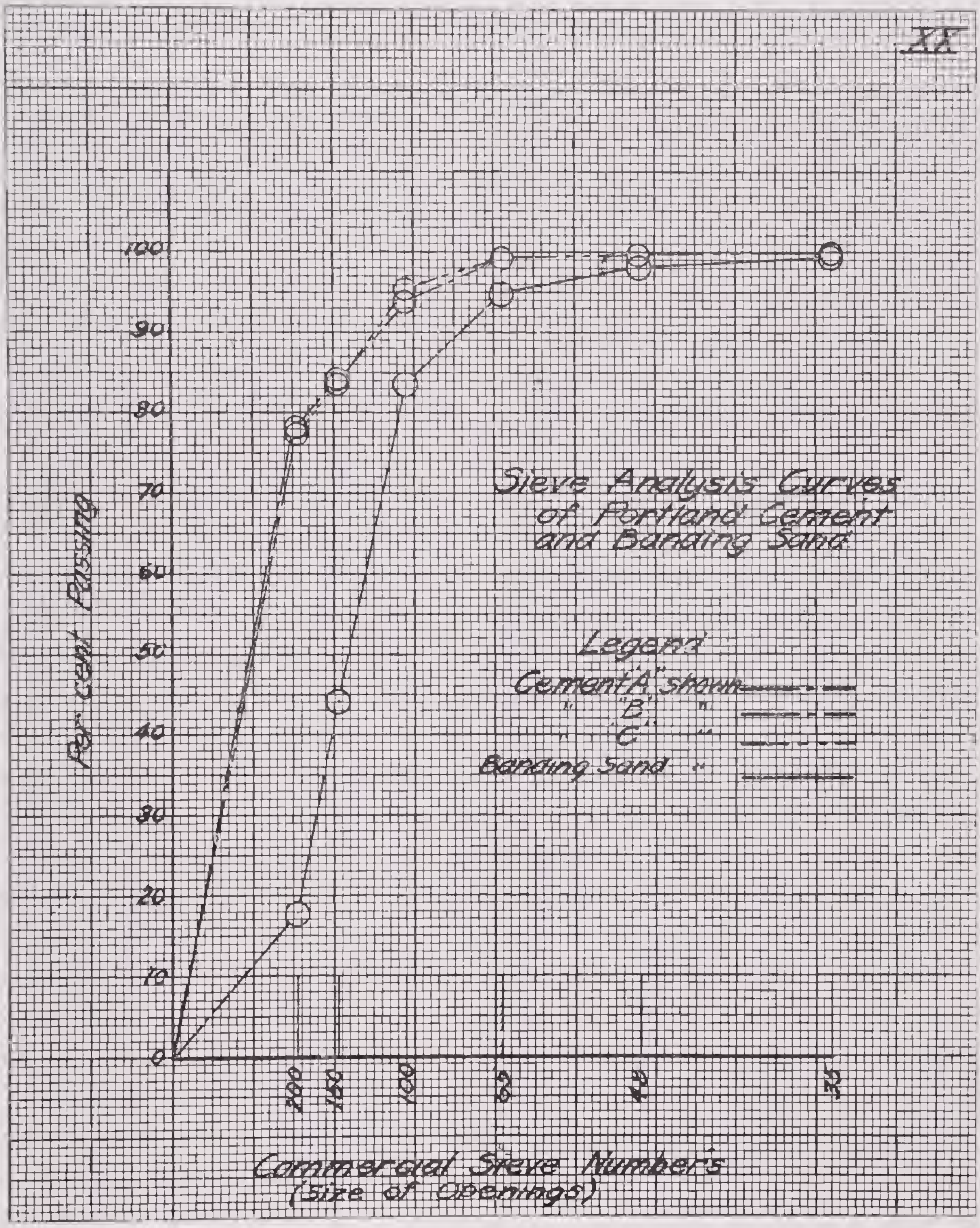
The usual tests, normal and accelerated, for the determinations of soundness were made. The standard methods suggested by the American Society of Civil Engineers were followed in these tests. The specimens were observed for periods of one year and in every instance the standard specifications were fulfilled. Each of the specimens remained true and sound throughout this entire period.

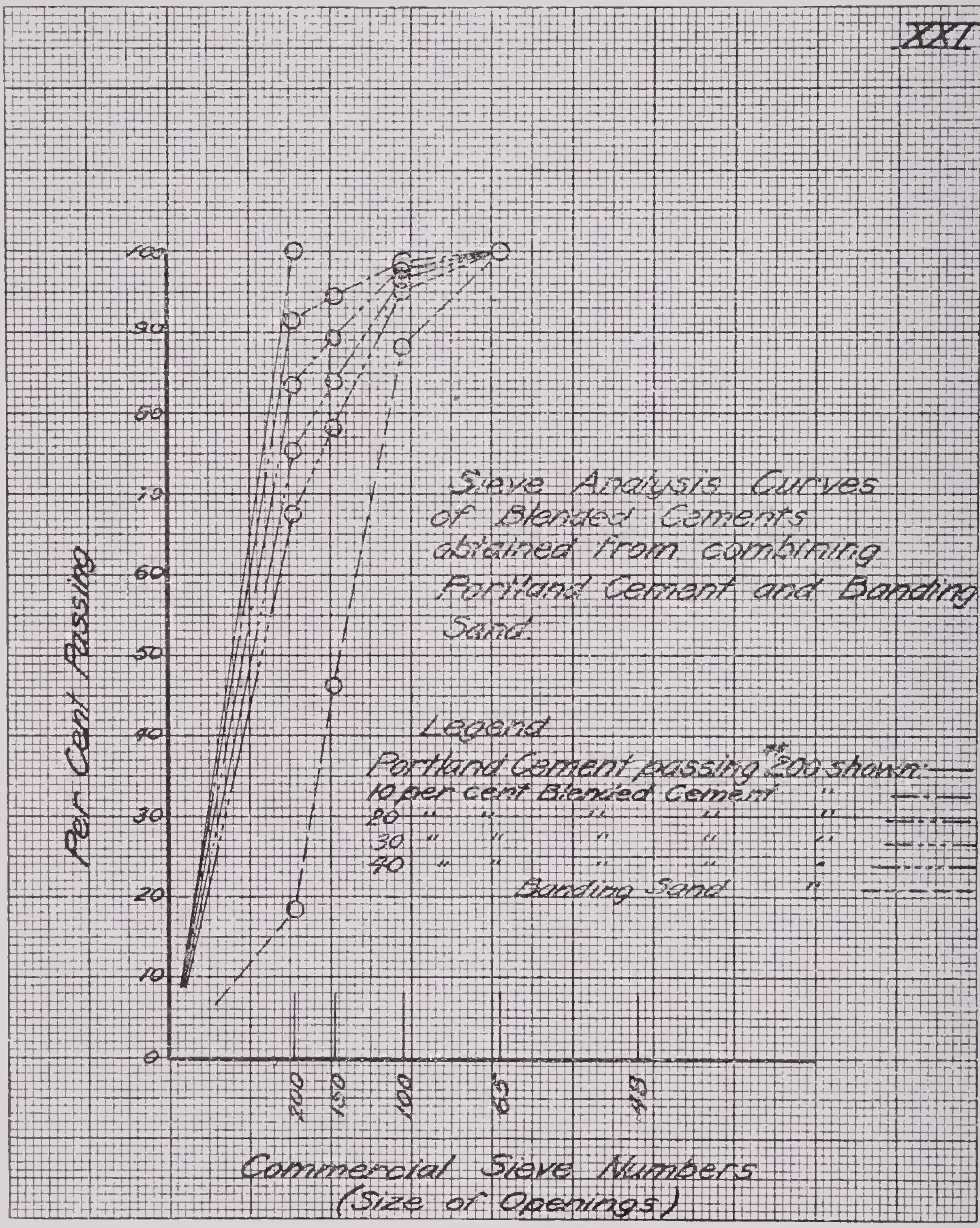
**(H) Fineness and Sieve Analysis.**

The curves of sieve analysis shown on Sheet XX were plotted from the data compiled in Table "D" (Appendix). It will be noted that the fineness of these Portland Cements easily satisfied the specifications of the American Society for Testing Materials and that there was but little difference in the gradation of the size of particles, cements A and B having almost identical curves of sieve analysis. The banding sand is shown to be well graded between the No. 65 and No. 200 sieves, this portion of the curve comparing favorably with the same portion of the Portland Cement curves. By combining this cement and sand, as has been previously indicated, that is, by using only that portion of the cement passing the No. 200 sieve and that portion of the sand passing the No. 65 sieve, a combined curve can be obtained which is quite similar to the Portland Cement curves. Curve Sheet XXI, therefore, has been prepared showing the gradation of the Portland Cement after the removal of the coarse particles (those retained upon a No. 200 sieve) and of the banding sand after the removal of particles larger than the No. 65 sieve openings. The combinations of these are shown as combined curves and are typical of the gradation of the blended cements. It will be noted here that the blended cement containing 30 per cent of sand has a gradation in size of particles almost identical with that of the Portland Cements. The data plotted on Curve Sheet XXI were computed but it is thought that they should reasonably approximate experimentally derived data.


XVIII
Time of Initial Set
Time in Hours
0
1
2
3
4
5
6
7
8
9
A
B
C
A A₁₀ A₂₀ A₃₀ A₄₀
B B₁₀ B₂₀ B₃₀ B₄₀
C C₁₀ C₂₀ C₃₀ C₄₀


XIX
Time of Final Set
Time in Hours
0
1
2
3
4
5
6
7
8
9
10
A
B
C
Av.
A $A_{10}$ $A_{20}$ $A_{30}$ $A_{40}$
B $B_{10}$ $B_{20}$ $B_{30}$ $B_{40}$
C $C_{10}$ $C_{20}$ $C_{30}$ $C_{40}$


XX
Sieve Analysis Curves of Portland Cement and Banding Sand
Legend
Cement "A" shown
" "B" "
" "C" "
Banding Sand "
Per cent Passing
100
90
80
70
60
50
40
30
20
10
0
200
150
100
60
48
35
Commercial Sieve Numbers (Size of Openings)


XXI
Sieve Analysis Curves of Blended Cements obtained from combining Portland Cement and Banding Sand.
Legend
Portland Cement passing #200 shown
10 per cent Blended Cement " "
20 " " " " "
30 " " " " "
40 " " " " "
Banding Sand "
Per Cent Passing
100
90
80
70
60
50
40
30
20
10
0
200
150
100
65
48
Commercial Sieve Numbers
(Size of Openings)

**(I) Chemical Analysis and Specific Gravity.**

The chemical analyses recorded in Table XVI are partly laboratory determinations and partly determinations arrived at by computation. The three commercial Portland Cements and the Banding Sand were analyzed by Mr. R. P. Rinker, Chemist for the Missouri Bureau of Geology and Mines, through the courtesy of Mr. H. A. Buehler, Director. Analyses were furnished by the various cement companies. The results obtained by Mr. Rinker and those furnished by the cement companies are so nearly identical that only those of the former are shown. The analyses of the various blended cements are the results of combining the analysis of the banding sand with the analysis of the Portland Cement blended in the ratio of the combination, sand to cement.

## SUMMARY

In summarizing the foregoing, the following observations have been noted:

**(A) Neat Cement in Tension.**

Portland Cement and blended cements gain in strength at approximately the same rate.

Portland Cement develops slightly greater strength at early periods of testing than does a blended cement.

At 24 and 52 weeks the 30 and 40 per cent blended cements are equal in strength to the Portland Cement, the 10 and 20 per cent blended cements showing to slightly less advantage.

**(B) Cement Mortar In Tension.**

The rate of gain in strength in Portland Cement mortar and blended cement mortar is approximately the same.

Within the scope of this investigation Portland Cement mortar is not superior in strength to blended cement mortar.

When the amount of blending material used does not exceed 30 per cent, blended cement mortar develops greater strength than does Portland Cement mortar.

**(C) Neat Cement In Compression**

The results obtained are unsatisfactory, owing to lack of uniformity.

When the amount of blending material used does not exceed 30 per cent, the relative strength of the blended cements compares favorably with that of commercial Portland Cement.

**(D) Cement Mortar In Compression.**

Within the scope of these tests Portland Cement mor-

tar develops greater strength than does blended cement mortar.

The strength of mortar varies inversely with the amount of blending material used.

When the amount of blending material does not exceed about 30 per cent, such blended cement mortar may be expected to pass satisfactorily the proposed specifications of the American Society for Testing Materials.

Note:—It seems unusual that the results obtained from testing cement mortars in tension are so contradictory to those obtained from testing similar cement mortars in compression; the former favoring the blended cements, while the latter show the Portland Cements to be superior in strength.

**(E) Normal Consistency.**

Within the scope of this investigation, Portland Cements differ in normal consistency within narrow limits.

The normal consistency of blended cements varies inversely with the amount of the blending material used.

**(F) Time of Setting.**

Within the scope of this investigation, Portland Cements differ in time of setting within wide limits.

Blended cements, having more than 20 per cent of blending material, seem to develop initial and final setting more slowly than do the Portland Cements of which they are composed.

Blended cements, having not to exceed 40 per cent of blending material, satisfy the requirements of the present standard specifications for the time of setting of Portland Cements.

**(G) Constancy of Volume.**

Blended cements, having not to exceed 40 per cent of blending material, satisfactorily meet the present standard specifications of Portland Cements for soundness.

**(H) Fineness and Sieve Analysis.**

Of the blended cements, those containing 30 per cent of sand most nearly approximate the Portland Cements in fineness and gradation of size of particles.

## CONCLUSIONS

Portland Cements, of a fineness sufficient to pass a No. 200 sieve, may be blended as much as 40 per cent, by weight, with quartz sand, the latter of a fineness sufficient to pass a No. 65 sieve but not fine enough to permit of more than 20 per cent to pass a No. 200 sieve, and the resulting blend-

ed cement will satisfactorily pass the requirements of the present standard specifications for Portland Cement of the American Society for Testing Materials.

Quartz sand is a satisfactory substitute for the inert clinker particles in Portland Cement in maintaining the present physical characteristics of the latter, when used in amounts not to exceed 30 per cent, by weight.

Note: It is obviously impracticable to manufacture blended cements commercially in a manner followed in this investigation. It is thought to be feasible, however, to accomplish this end by incorporating the sand in the cement just prior to final grinding. Such procedure, it is thought, would have several advantages over the methods used here. It is thought that the reduction of the cement clinker in fineness much in excess of that attained at present would result and also that a more thorough mixing of the sand and cement would be accomplished than by any other method. With a view of ascertaining to what extent these assumptions are correct and also to what extent the blending of Portland Cement with quartz sand may be carried, an investigation has been started in which the Portland Cement is mixed with the sand in a tube mill and the grinding continued until a high percentage of the cement clinker is reduced to cement. The results of this investigation will appear in a subsequent bulletin.

## CHEMICAL ANALYSIS AND SPECIFIC GRAVITY

### Analysis of Cements

| Cement Serial Number | Ignition Loss | Percentage of: | | | | | | | Sp. Gr. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $SiO_2$ | $Fe_2O_3$ | $Al_2O_3$ | CaO | MgO | $SO_3$ | Total | Computed | Determine |
| A | 1.80 | 21.48 | 2.57 | 5.89 | 63.32 | 3.00 | 1.50 | 100.06 | | 3.184 |
| $A_{10}$ | 1.65 | 29.64 | 2.28 | 5.30 | 56.97 | 2.70 | 1.30 | 99.90 | 3.135 | |
| $A_{20}$ | 1.50 | 37.31 | 2.02 | 4.86 | 50.66 | 2.40 | 1.20 | 99.95 | 3.084 | |
| $A_{30}$ | 1.35 | 44.88 | 1.89 | 4.33 | 44.33 | 2.10 | 1.05 | 99.93 | 3.033 | |
| $A_{40}$ | 1.21 | 52.65 | 1.66 | 3.81 | 38.01 | 1.80 | 0.90 | 100.04 | 2.984 | |
| B | 1.80 | 21.46 | 2.85 | 6.81 | 63.56 | 2.10 | 1.46 | 100.04 | | 3.176 |
| $B_{10}$ | 1.65 | 29.18 | 2.59 | 6.20 | 57.21 | 1.89 | 1.31 | 100.03 | 3.126 | |
| $B_{20}$ | 1.50 | 36.90 | 2.31 | 5.58 | 50.85 | 1.68 | 1.17 | 99.99 | 3.076 | |
| $B_{30}$ | 1.35 | 44.62 | 2.09 | 4.97 | 44.49 | 1.47 | 1.02 | 100.01 | 3.028 | |
| $B_{40}$ | 1.21 | 52.32 | 1.83 | 4.36 | 38.14 | 1.26 | .87 | 99.99 | 2.977 | |
| C | 0.60 | 22.70 | 3.07 | 7.55 | 63.58 | 1.22 | 1.53 | 99.85 | | 3.208 |
| $C_{10}$ | .57 | 30.08 | 2.79 | 6.87 | 56.80 | 1.09 | 1.37 | 99.57 | 3.155 | |
| $C_{20}$ | .54 | 37.88 | 2.51 | 6.18 | 50.61 | .97 | 1.22 | 99.91 | 3.102 | |
| $C_{30}$ | .52 | 45.49 | 2.24 | 5.49 | 44.21 | .85 | 1.07 | 99.87 | 3.049 | |
| $C_{40}$ | .49 | 53.08 | 1.96 | 4.81 | 37.91 | .73 | .91 | 99.89 | 2.996 | |
| Banding Sand | .32 | 98.66 | .31 | .69 | .04 | | | 100.02 | | 2.681 |

## RESULTS OF TENSION TESTS

(Neat Specimens)

| Series No. | Specimen made 1915 | 24 hours | 7 days | 28 days | 56 days | 84 days | 24 weeks | 52 weeks | 104 weeks |
|---|---|---|---|---|---|---|---|---|---|
| | | 295 | 743 | 843 | 769 | 755 | 830 | 671 | |
| B | 12-20 | 325 | 812 | 784 | 783 | 943 | 635 | 686 | |
| | | 312 | 768 | 861 | 722 | 875 | 696 | 739 | |
| Avr. | | 317 | 779 | 855 | 758 | 789 | 744 | 728 | |
| | | 311 | 797 | 802 | 802 | 912 | 762 | 687 | |
| B | 12-20 | 325 | 812 | 784 | 783 | 943 | 635 | 686 | |
| | | 282 | 835 | 878 | 815 | 784 | 768 | 670 | |
| Avr. | | 306 | 815 | 821 | 801 | 883 | 722 | 681 | |
| | | 400 | 710 | 758 | 758 | 711 | 590 | 642 | |
| C | 12-20 | 405 | 612 | 790 | 727 | 737 | 647 | 562 | |
| | | 375 | 745 | 789 | 788 | 788 | 673 | 511 | |
| Avr. | | 393 | 686 | 779 | 758 | 745 | 636 | 572 | |
| | | 325 | 637 | 635 | 677 | 679 | 627 | 610 | |
| $A_{10}$ | 12-23 | 332 | 463 | 674 | | 736 | 583 | 598 | |
| | | 308 | 512 | 738 | 656 | 719 | 557 | 560 | |
| Avr. | | 322 | 537 | 682 | 666 | 711 | 589 | 589 | |
| | | 388 | 544 | 645 | 791 | 714 | 683 | 677 | |
| $B_{10}$ | 12-23 | 370 | 721 | 753 | 793 | 761 | 675 | 617 | |
| | | 340 | 712 | | 790 | 651 | 676 | 553 | |
| Avr. | | 366 | 666 | 699 | 792 | 708 | 678 | 616 | |
| | | 320 | 521 | 765 | 662 | 686 | 635 | 412 | |
| $C_{10}$ | 12-22 | 295 | 648 | 751 | 724 | 688 | 593 | 414 | |
| | | 288 | 720 | | 713 | 610 | 600 | 485 | |
| Avr. | | 301 | 630 | 758 | 700 | 681 | 608 | 434 | |
| | | 235 | 777 | 755 | 745 | 763 | 731 | 640 | |
| $A_{20}$ | 12-27 | 274 | 733 | | 680 | 764 | 774 | 633 | |
| | | 220 | 745 | 675 | 789 | 792 | 720 | 765 | |
| Avr. | | 243 | 752 | 715 | 738 | 773 | 742 | 679 | |
| | | 323 | 716 | 900 | 750 | 784 | 776 | 590 | |
| $B_{20}$ | 12-27 | 364 | 726 | 902 | 662 | 796 | 747 | 554 | |
| | | 320 | 759 | 777 | 794 | 797 | 706 | 552 | |
| Avr. | | 332 | 733 | 859 | 735 | 792 | 743 | 565 | |
| | | 327 | 561 | | 620 | 714 | 686 | 551 | |
| $C_{20}$ | 12-27 | 314 | 603 | 613 | 623 | 672 | 626 | 487 | |
| | | 277 | 667 | 652 | 600 | 724 | 579 | 498 | |
| Avr. | | 306 | 610 | 622 | 614 | 703 | 630 | 512 | |
| | | 225 | 622 | 744 | 872 | 747 | 726 | 762 | |
| $A_{30}$ | 12-29 | 303 | 680 | 820 | 865 | 777 | 790 | 675 | |
| | | 305 | 670 | 750 | 812 | 674 | | 776 | |
| Avr. | | 278 | 657 | 771 | 849 | 732 | 758 | 738 | |
| | | 249 | 630 | 797 | 714 | 720 | 775 | 776 | |
| $B_{30}$ | 12-29 | 272 | 730 | 731 | 830 | 688 | 682 | 697 | |
| | | 255 | 593 | 762 | 778 | 700 | 765 | 717 | |
| Avr. | | 259 | 651 | 763 | 774 | 702 | 741 | 730 | |
| | | 182 | 579 | 664 | 784 | 577 | 620 | 622 | |
| $B_{30}$ | 12-28 | 177 | 559 | 544 | 730 | 627 | 702 | 580 | |
| | | 175 | 634 | 615 | 620 | 618 | 658 | 564 | |
| Avr. | | 178 | 591 | 607 | 711 | 607 | 660 | 588 | |
| | | 325 | | 777 | 767 | 797 | 736 | 735 | |
| $A_{40}$ | 12-30 | 300 | 629 | 791 | 759 | 725 | 781 | 690 | |
| | | 305 | 694 | 693 | 719 | 793 | 765 | 743 | |
| Avr. | | 310 | 662 | 754 | 748 | 771 | 761 | 722 | |
| | | 265 | 583 | 651 | 735 | 748 | 633 | 644 | |
| $B_{40}$ | 12-29 | | 482 | 685 | 775 | 705 | 743 | 697 | |
| | | | 576 | 631 | 820 | 682 | 704 | 702 | |
| Avr. | | 265 | 547 | 655 | 777 | 711 | 693 | 681 | |
| | | 186 | 525 | 560 | 730 | 628 | 679 | 606 | |
| $C_{40}$ | 12-30 | 208 | 525 | 678 | 679 | 611 | 661 | 616 | |
| | | 205 | 485 | 672 | 711 | 694 | 603 | 639 | |
| Avr. | | 200 | 511 | 637 | 706 | 644 | 648 | 618 | |
| Average of Averages | | | | | | | | | |
| A - B - C | | 335 | 760 | 818 | 772 | 806 | 701 | 660 | |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | 330 | 611 | 713 | 719 | 700 | 625 | 546 | |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | 294 | 692 | 732 | 702 | 756 | 705 | 585 | |
| $A_{30}$ - $B_{30}$ - $C_{30}$ | | 238 | 633 | 714 | 778 | 780 | 720 | 685 | |
| $A_{40}$ - $B_{40}$ - $C_{40}$ | | 258 | 573 | 682 | 758 | 709 | 701 | 673 | |
| Average of Highest Breaks | | | | | | | | | |
| A - B - C | | 358 | 802 | 843 | 759 | 869 | 757 | 701 | |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | 347 | 693 | 752 | 731 | 728 | 648 | 590 | |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | 322 | 713 | 770 | 735 | 771 | 745 | 635 | |
| $A_{30}$ - $B_{30}$ - $C_{30}$ | | 253 | 681 | 760 | 829 | 708 | 756 | 725 | |
| $A_{40}$ - $B_{40}$ - $C_{40}$ | | 266 | 601 | 718 | 772 | 746 | 734 | 694 | |

## RESULTS OF TENSION TESTS

(Mortar Specimens)

| Series No. | Spec's made 1915-1916 | Stress in Pounds per Square Inch | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 7 days | 28 days | 56 days | 84 days | 24 weeks | 52 weeks | 104 weeks |
| | | 192 | 257 | 340 | 339 | 313 | 278 | |
| A | 12-21 | 165 | 288 | 322 | 343 | 321 | 251 | |
| | | 200 | 322 | 314 | 357 | 299 | 241 | |
| Avr. | | 186 | 289 | 325 | 346 | 310 | 247 | |
| | | 192 | 332 | 345 | 389 | 378 | 360 | |
| B | 12-21 | 175 | 348 | 381 | 402 | 362 | 340 | |
| | | 224 | 339 | 383 | 361 | 369 | 366 | |
| Avr. | | 197 | 339 | 369 | 384 | 369 | 355 | |
| | | 213 | 362 | 392 | 462 | 445 | 365 | |
| C | 12-21 | 228 | 366 | 387 | 466 | 435 | 407 | |
| | | 254 | 395 | 369 | 485 | | 370 | |
| Avr. | | 232 | 374 | 382 | 471 | 440 | 381 | |
| | | 334 | 462 | 527 | 524 | 532 | 404 | |
| $A_{10}$ | 12-31 | 337 | 443 | 428 | 476 | 475 | 411 | |
| | | 343 | 375 | 428 | 523 | 452 | 374 | |
| Avr. | | 338 | 427 | 461 | 508 | 486 | 396 | |
| | | 311 | 413 | 412 | 449 | 432 | 481 | |
| $B_{10}$ | 12-31 | 294 | 366 | 426 | 447 | 435 | 492 | |
| | | 285 | 496 | 522 | 487 | 429 | 466 | |
| Avr. | | 297 | 425 | 453 | 461 | 432 | 479 | |
| | | 320 | 325 | 351 | 457 | | 380 | |
| $C_{10}$ | 12-30 | 230 | 304 | 414 | 511 | 523 | 504 | |
| | | 273 | 337 | | 416 | 390 | 326 | |
| Avr. | | 274 | 322 | 383 | 461 | 457 | 403 | |
| | | 308 | 417 | 475 | 389 | 441 | 400 | |
| $A_{20}$ | 12-31 | 252 | 404 | 448 | 404 | 431 | 397 | |
| | | 257 | 396 | 453 | 458 | 483 | 408 | |
| Avr. | | 272 | 405 | 459 | 417 | 452 | 402 | |
| | | 284 | 422 | 430 | 408 | 448 | 388 | |
| $B_{20}$ | 12-31 | 299 | 405 | 400 | 476 | 421 | 400 | |
| | | 248 | 428 | 439 | 462 | 434 | 384 | |
| Avr. | | 277 | 418 | 423 | 448 | 434 | 391 | |
| | | 273 | 460 | 373 | 426 | 373 | 389 | |
| $C_{20}$ | 12-31 | 257 | 416 | 427 | 491 | 375 | 388 | |
| | | 268 | 381 | 455 | 468 | 411 | 392 | |
| Avr. | | 266 | 419 | 418 | 462 | 386 | 389 | |
| | | 220 | 381 | 400 | 484 | 413 | 370 | |
| $A_{30}$ | 1-1 | 220 | 367 | 350 | 426 | 452 | 362 | |
| | | 237 | 327 | 431 | 411 | 433 | 409 | |
| Avr. | | 225 | 358 | 393 | 440 | 433 | 377 | |
| | | 252 | 306 | 409 | 429 | 369 | 372 | |
| $B_{30}$ | 1-1 | 232 | 346 | 344 | 361 | 437 | 343 | |
| | | 262 | 350 | 435 | 451 | 403 | 383 | |
| Avr. | | 248 | 334 | 396 | 413 | 403 | 366 | |
| | | 248 | 365 | 346 | 444 | 417 | 354 | |
| $C_{30}$ | 1-1 | 260 | 382 | 476 | 414 | 407 | 389 | |
| | | 267 | 340 | 402 | 385 | 460 | 389 | |
| Avr. | | 258 | 362 | 408 | 414 | 425 | 377 | |
| | | 181 | 356 | 371 | 381 | 360 | 385 | |
| $A_{40}$ | 1-1 | 221 | 339 | 356 | 364 | 357 | 298 | |
| | | 203 | 328 | 354 | 302 | 337 | 309 | |
| Avr. | | 201 | 341 | 360 | 349 | 351 | 331 | |
| | | 187 | 318 | 308 | 372 | 342 | 314 | |
| $B_{40}$ | 1-1 | 194 | 338 | 358 | 332 | 391 | 332 | |
| | | 203 | 318 | 362 | 403 | 356 | 345 | |
| Avr. | | 194 | 324 | 343 | 362 | 363 | 330 | |
| | | 181 | 382 | 342 | 421 | 357 | 314 | |
| $C_{40}$ | 1-1 | 218 | 362 | 375 | 392 | 387 | 329 | |
| | | 185 | 352 | 360 | 409 | 386 | 326 | |
| Avr. | | 194 | 365 | 359 | 407 | 373 | 323 | |
| Average of Averages | | | | | | | | |
| A - B - C | | 205 | 334 | 359 | 400 | 373 | 331 | |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | 303 | 391 | 432 | 477 | 458 | 426 | |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | 272 | 413 | 433 | 442 | 424 | 394 | |
| $A_{30}$ - $B_{30}$ - $C_{30}$ | | 244 | 351 | 399 | 422 | 420 | 373 | |
| $A_{40}$ - $B_{40}$ - $C_{40}$ | | 196 | 342 | 354 | 375 | 362 | 328 | |
| Average of Highest Breaks | | | | | | | | |
| A - B - C | | 226 | 355 | 372 | 415 | 381 | 350 | |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | 325 | 428 | 467 | 507 | 497 | 436 | |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | 293 | 435 | 456 | 475 | 447 | 366 | |
| $A_{30}$ - $B_{30}$ - $C_{30}$ | | 255 | 371 | 447 | 460 | 450 | 393 | |
| $A_{40}$ - $B_{40}$ - $C_{40}$ | | 208 | 359 | 369 | 402 | 379 | 352 | |

# RESULTS OF COMPRESSION TESTS

| Series No. | Spec'c made | Stress in pounds per Square Inch | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 4 weeks Neat | 4 weeks Mortar | 12 weeks Neat | 12 weeks Mortar | 24 weeks Neat | 24 weeks Mortar | 52 weeks Neat | 52 weeks Mortar |
| | | 5480 | 3920 | 6490 | 5220 | 6930 | 5020 | 9188 | 3809 |
| A | | 7220 | 3360 | 7960 | 4540 | 11050 | 3380 | 8945 | 3304 |
| | | 5800 | 3620 | 8860 | 5170 | 6110 | 4020 | | 5056 |
| Avr. | | 6170 | 3633 | 7470 | 4980 | 8030 | 4140 | 9066 | 4456 |
| | | 5280 | 3200 | 10380 | 3780 | 6470 | 4180 | 7984 | 3859 |
| B | | 6850 | 3390 | 8380 | 4040 | 4440 | 5500 | 7898 | 4140 |
| | | 6980 | 3700 | 6700 | 3380 | 6890 | 3860 | 9159 | 3252 |
| Avr. | | 6370 | 3430 | 8487 | 3730 | 5930 | 4840 | 8347 | 3750 |
| | | 4550 | 4060 | 6790 | 4720 | 7920 | 4200 | 6944 | 4350 |
| C | | 6610 | 3920 | 6500 | 4680 | 8830 | 3550 | 8259 | 3772 |
| | | 5520 | 3540 | 9520 | 5100 | 7050 | 4220 | 7337 | 4912 |
| Avr. | | 5560 | 3840 | 7603 | 4830 | 7930 | 3990 | 7513 | 4345 |
| | | 6590 | 3010 | 6250 | 2580 | 7780 | 4020 | 3844 | 3782 |
| A - 10 | | 6430 | 3420 | 6860 | 4630 | 8640 | 4510 | 5611 | 3679 |
| | | 4400 | 3560 | 9520 | 3720 | 8060 | 4530 | 5245 | 3820 |
| Avr. | | 5810 | 3330 | 7543 | 3640 | 8160 | 4350 | 4900 | 3760 |
| | | 6120 | 2700 | 11000 | 3590 | 7220 | 4460 | 7961 | 4331 |
| B - 10 | | 6450 | 2900 | 9980 | 5070 | 6520 | 2840 | 7996 | 3327 |
| | | 6400 | 2870 | 10860 | 3640 | 7160 | 4250 | 8314 | 4948 |
| Avr. | | 6320 | 2823 | 10613 | 4120 | 6970 | 3850 | 8090 | 4202 |
| | | 5500 | 2660 | 7980 | 4010 | 7690 | 2580 | 5615 | 3025 |
| C - 10 | | 4660 | 3320 | 6200 | 2710 | 7780 | 4660 | 5117 | 4537 |
| | | 1110 | 8500 | 7940 | 3220 | 8380 | 4310 | 6565 | 3440 |
| Avr. | | 5610 | 2827 | 7373 | 3310 | 7950 | 3850 | 5766 | 3667 |
| | | 6280 | 3830 | 6200 | 4300 | 7230 | 4140 | 8143 | 3812 |
| A - 20 | | 6470 | 2950 | 6960 | 4280 | 5170 | 3870 | 7258 | 4069 |
| | | 8700 | 2850 | 9070 | 3740 | 8350 | 2780 | 8888 | 4320 |
| Avr. | | 7150 | 3210 | 7410 | 4110 | 6920 | 3600 | 8096 | 4067 |
| | | 6450 | 3040 | 4800 | 3330 | 9120 | 2890 | 6464 | 3166 |
| B - 20 | | 6130 | 2750 | 8210 | 3430 | 7030 | 2550 | 5166 | 3720 |
| | | 7340 | 2620 | 8070 | 3220 | 7830 | 3040 | 4149 | 3700 |
| Avr. | | 6640 | 2803 | 7026 | 3330 | 7993 | 2830 | 5259 | 3529 |
| | | 9610 | | 8220 | 3200 | 7180 | 2600 | 6904 | 2184 |
| C - 20 | | 7370 | 1860 | 4160 | 3150 | 8720 | 2060 | 6493 | 2884 |
| | | 7480 | 2590 | 5520 | 3220 | 8680 | 2760 | 8522 | 2740 |
| Avr. | | 8150 | 2590 | 5966 | 3190 | 8190 | 2470 | 7306 | 2607 |
| | | 6560 | 2500 | 6640 | 2950 | 8510 | 3540 | 8624 | 2260 |
| A - 30 | | 6200 | 1710 | 6870 | 3350 | 7840 | 2400 | 5165 | 3398 |
| | | 6370 | 1890 | 6530 | 3110 | 7130 | 3230 | 7382 | 2220 |
| Avr. | | 6320 | 2033 | 6680 | 3140 | 7830 | 3060 | 7057 | 2626 |
| | | 6780 | 2340 | 7000 | 2850 | 7910 | 2510 | 8429 | 1834 |
| B - 30 | | 6180 | 2300 | 6970 | 3590 | 9620 | 2530 | 4914 | 2672 |
| | | 6120 | 2050 | 4510 | 3050 | 8530 | 3840 | 6149 | 3268 |
| Avr. | | 6360 | 2230 | 6160 | 3160 | 8690 | 3250 | 6497 | 2591 |
| | | 5820 | 1550 | 5610 | 3220 | 9470 | 3770 | 7442 | 2039 |
| C - 30 | | 5360 | 1940 | 7800 | 3220 | 9450 | 2450 | 8746 | 2857 |
| | | 5860 | 1250 | 7730 | 2930 | 7840 | 3490 | 8063 | 2144 |
| Avr. | | 5640 | 1580 | 7050 | 3120 | 8920 | 3240 | 8083 | 2347 |
| | | | 1640 | 4770 | 2270 | 9950 | 1750 | 4516 | 2032 |
| A - 40 | | 4800 | 1560 | 5320 | 2970 | 4720 | 2840 | 4812 | 2975 |
| | | 6540 | 2320 | 6700 | 3120 | 5010 | 2980 | 6369 | 2680 |
| Avr. | | 5670 | 1840 | 5609 | 2790 | 6560 | 2520 | 5232 | 2562 |
| | | 7070 | 1900 | 4840 | 1900 | 6960 | 2930 | 5843 | 1904 |
| B - 40 | | 5529 | 1760 | 7360 | 2090 | 7380 | 2270 | 4458 | 1870 |
| | | 6120 | 2040 | 1370 | 2260 | 6750 | 2040 | 7418 | 2260 |
| Avr. | | 6280 | 1900 | 6520 | 2080 | 7030 | 2410 | 5906 | 2011 |
| | | 4710 | 1030 | 7700 | 2500 | 8710 | 2320 | 5828 | 2047 |
| C - 40 | | 5470 | 1820 | 6360 | 2930 | 7340 | 2010 | 5240 | 1428 |
| | | 6110 | 1560 | 6490 | 1870 | 6820 | 2040 | 6380 | 2282 |
| Avr. | | 5450 | 1470 | 6850 | 2433 | 7620 | 2040 | 5816 | 1919 |
| Average of Averages | | | | | | | | | |
| A, B & C | | 6033 | 3634 | 7853 | 4510 | 7300 | 4320 | 8309 | 4050 |
| A-10, B-10, C-10 | | 5913 | 2993 | 8509 | 3690 | 7690 | 4020 | 6252 | 3876 |
| A-20, B-20, C-20 | | 7310 | 2868 | 6800 | 3540 | 7700 | 2970 | 6887 | 3401 |
| A-30, B-30, C-30 | | 6100 | 1944 | 6630 | 3140 | 8480 | 3180 | 7212 | 2521 |
| A-40, B-40, C-40 | | 5793 | 1737 | 6320 | 2101 | 7070 | 2320 | 5651 | 2164 |
| Average of Highest Breaks | | | | | | | | | |
| A, B, & C | | 6937 | 3890 | 9590 | 4790 | 8920 | 4910 | 8869 | 4703 |
| $A_{10}$, $B_{10}$ & $C_{10}$ | | 6567 | 3260 | 9500 | 4570 | 8080 | 4550 | 6691 | 4435 |
| $A_{20}$, $B_{20}$ & $C_{20}$ | | 8550 | 3150 | 8500 | 4660 | 8730 | 3310 | 7958 | 3641 |
| $A_{30}$, $B_{30}$ & $C_{30}$ | | 6400 | 2260 | 7220 | 3390 | 9200 | 3720 | 8600 | 3174 |
| $A_{40}$, $B_{40}$ & $C_{40}$ | | 6573 | 2060 | 7260 | 2770 | 8540 | 2740 | 6722 | 2506 |

## RESULTS OF COMPRESSION TESTS

(Neat Specimens)

**Tested at age of 24 weeks**

| Series No. | Spec'c made 1916 Date | Dim'nsions Height inches | Diam. inches | Area in Sq. in. | Vol. in Cu. in. | Weight Total Gms. | Unit Gms. | Load 1st Cr. lbs. | Ult. lbs. | Stress 1st Cr. lb./sq. in | Ult. lb./sq. in |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2.04 | 2.02 | 3.20 | 6.53 | 237 | 36.30 | 17740 | 22190 | 5550 | 6930 |
| A | 1-29 | 2.04 | 2.00 | 3.14 | 6.41 | 239 | 37.30 | 20220 | 34740 | 6450 | 11050 |
| | | 2.03 | 2.01 | 3.17 | 6.44 | 239 | 37.12 | 18660 | 19360 | 5880 | 6110 |
| Avr. | | | | | | | | 18873 | 25430 | 5960 | 8030 |
| | | 2.03 | 2.02 | 3.20 | 6.50 | 238 | 36.64 | 15490 | 20690 | 4840 | 6470 |
| B | 1-29 | 2.02 | 2.02 | 3.20 | 6.47 | 234 | 36.18 | 8720 | 14190 | 2720 | 4440 |
| | | 2.04 | 2.02 | 3.20 | 6.53 | 237 | 36.30 | 16820 | 22020 | 5260 | 6890 |
| Avr. | | | | | | | | 13677 | 18967 | 4270 | 5930 |
| | | 2.08 | 2.02 | 3.20 | 6.66 | 237 | 35.59 | 19830 | 25320 | 6200 | 1920 |
| C. | 1-29 | 2.08 | 2.02 | 3.20 | 6.66 | 226 | 33.92 | 25150 | 28240 | 7860 | 8830 |
| | | 2.02 | 2.04 | 3.27 | 6.61 | 238 | 36.01 | 23050 | 23050 | 7050 | 7050 |
| Avr. | | | | | | | | 22677 | 25537 | 7040 | 7930 |
| | | 2.08 | 2.02 | 3.20 | 6.66 | 236 | 35.45 | 11450 | 24870 | 3580 | 7780 |
| $A_{10}$ | 1-31 | 2.05 | 2.04 | 3.27 | 6.70 | 236 | 35.25 | 10110 | 28230 | 3090 | 8640 |
| | | 2.01 | 2.01 | 3.17 | 6.37 | 220 | 34.52 | 23840 | 25570 | 7530 | 8060 |
| Avr. | | | | | | | | 15133 | 26223 | 4730 | 8160 |
| | | 1.98 | 1.98 | 3.08 | 6.10 | 212 | 34.78 | 12560 | 22210 | 4080 | 7220 |
| $B_{10}$ | 2-2 | 2.01 | 2.00 | 3.14 | 6.31 | 215 | 34.08 | 17200 | 20480 | 5480 | 6520 |
| | | 2.02 | 1.97 | 3.05 | 6.16 | 216 | 35.07 | 15030 | 21810 | 4930 | 7160 |
| Avr. | | | | | | | | 14930 | 21500 | 4830 | 6970 |
| | | 2.06 | 2.04 | 3.27 | 6.78 | 237 | 34.97 | 25080 | 25140 | 7680 | 7690 |
| $C_{10}$ | 1-31 | 2.06 | 2.02 | 3.20 | 6.59 | 240 | 36.42 | 18530 | 24910 | 5800 | 7780 |
| | | 2.06 | 2.03 | 3.25 | 6.65 | 240 | 36.10 | 19000 | 27030 | 5890 | 8380 |
| Avr. | | | | | | | | 20870 | 25693 | 6460 | 7950 |
| | | 2.10 | 2.01 | 3.17 | 6.66 | 238 | 35.77 | 19330 | 22890 | 6100 | 7230 |
| $A_{20}$ | 2-2 | 2.00 | 2.02 | 3.20 | 6.69 | 240 | 35.90 | 10650 | 16510 | 3330 | 5170 |
| | | 2.06 | 2.02 | 3.20 | 6.59 | 238 | 36.14 | 15590 | 26710 | 4870 | 8350 |
| Avr. | | | | | | | | 15190 | 22037 | 4770 | 6920 |
| | | 2.05 | 2.04 | 3.27 | 6.70 | 232 | 34.63 | 19920 | 29810 | 6100 | 9120 |
| $B_{20}$ | 2-3 | 2.06 | 2.02 | 3.20 | 6.59 | 230 | 34.92 | 11470 | 22470 | 7030 | 7030 |
| | | 2.03 | 2.00 | 3.14 | 6.37 | 217 | 34.08 | 11340 | 24606 | 3620 | 7830 |
| Avr. | | | | | | | | 17910 | 25627 | 5580 | 7993 |
| | | 2.01 | 2.00 | 3.14 | 6.31 | 221 | 35.05 | 12620 | 22530 | 4020 | 7180 |
| $C_{20}$ | 2-16 | 2.00 | 2.04 | 3.27 | 6.54 | 234 | 35.77 | 16940 | 28430 | 5180 | 8720 |
| | | 2.01 | 1.98 | 3.08 | 6.19 | 219 | 35.40 | 22490 | 26740 | 7300 | 8680 |
| Avr. | | | | | | | 35.40 | 17350 | 25900 | 5500 | 8190 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 219 | 34.88 | 23000 | 26690 | 7330 | 8510 |
| $A_{30}$ | 2-16 | 2.00 | 1.99 | 3.11 | 6.22 | 220 | 35.35 | 20890 | 24610 | 6720 | 7840 |
| | | 2.04 | 2.02 | 3.20 | 6.53 | 232 | 35.51 | 5130 | 22800 | 1600 | 7130 |
| Avr. | | | | | | | | 16340 | 24720 | 5220 | 7830 |
| | | 2.03 | 2.03 | 3.23 | 6.56 | 227 | 34.61 | 23840 | 25550 | 7380 | 7910 |
| $B_{30}$ | 2-16 | 2.02 | 2.02 | 2.20 | 6.47 | 228 | 35.25 | 30770 | 30770 | 9620 | 9620 |
| | | 2.01 | 1.99 | 3.11 | 6.25 | 217 | 34.72 | 22080 | 26510 | 7110 | 8530 |
| Avr. | | | | | | | | 25563 | 27603 | 8040 | 8690 |
| | | 2.00 | 2.04 | 3.27 | 6.54 | 232 | 35.48 | 30980 | 30980 | 9470 | 9470 |
| $C_{30}$ | 2-17 | 2.00 | 1.97 | 3.05 | 6.10 | 217 | 35.59 | 30870 | 30870 | 9450 | 4950 |
| | | 2.00 | 1.98 | 3.08 | 6.16 | 220 | 35.72 | 21800 | 24130 | 7080 | 7840 |
| Avr. | | | | | | | | 27885 | 28660 | 8670 | 8920 |
| | | 2.04 | 2.02 | 3.20 | 6.53 | 232 | 35.53 | 31840 | 31840 | 9950 | 9950 |
| $A_{40}$ | 2-19 | 2.08 | 1.98 | 3.08 | 6.25 | 217 | 34.74 | | 14520 | | 4720 |
| | | 2.04 | 2.05 | 3.30 | 6.73 | 232 | 34.50 | 7580 | 16520 | 2290 | 5010 |
| Avr. | | | | | | | | 19710 | 20960 | 6120 | 6560 |
| | | 2.02 | 1.99 | 3.11 | 6.28 | 219 | 34.88 | 19450 | 21610 | 6260 | 6960 |
| $B_{40}$ | 2-19 | 2.01 | 1.99 | 3.11 | 6.25 | 217 | 34.74 | 20340 | 22970 | 6530 | 7380 |
| | | 2.02 | 2.00 | 3.14 | 6.35 | 217 | 34.20 | 15329 | 21180 | 4880 | 6750 |
| Avr. | | | | | | | | 18370 | 21920 | 5890 | 7030 |
| | | 2.04 | 2.04 | 3.27 | 6.67 | 235 | 35.23 | 28450 | 28450 | 8710 | 8710 |
| $C_{40}$ | 2-23 | 2.01 | 2.00 | 3.14 | 6.32 | 223 | 35.30 | 23040 | 23040 | 7340 | 7340 |
| | | 2.04 | 2.00 | 3.14 | 6.41 | 224 | 34.94 | 21720 | 21720 | 6820 | 6820 |
| Avr. | | | | | | | | 24403 | 24403 | 7620 | 7620 |
| Average of Averages | | | | | | | | | | | |
| A - B - C | | | | | | | | | | 5760 | 7300 |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | | | | | | | | | 5340 | 7690 |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | | | | | | | | | 5280 | 7700 |
| $A_{30}$ - $B_{60}$ - $C_{30}$ | | | | | | | | | | 7310 | 8480 |
| $A_{40}$ - $B_{40}$ - $C_{40}$ | | | | | | | | | | 6540 | 7070 |
| Average of Highest Breaks | | | | | | | | | | | |
| A - B - C | | | | | | | | | | 6520 | 8920 |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | | | | | | | | | 6900 | 8080 |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | | | | | | | | | 6810 | 8720 |
| $A_{30}$ - $B_{30}$ - $C_{30}$ | | | | | | | | | | 8810 | 9200 |
| $A_{40}$ - $A_{40}$ - $C_{40}$ | | | | | | | | | | 8400 | 8540 |

# RESULTS OF COMPRESSION TESTS

(Mortar Specimens)

## Tested at age of 52 weeks

| Series No. | Spec'c made 1916 Date | Dim'nsion | | | | Weight | | Load | | Stress | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Diam. inches | Height inches | Area in Sq. in. | Vol. in Cu. in. | Total Gms. | Unit Gms. | 1st Cr. lbs. | Ult. lbs. | 1st Cr. lb./sq. in | Ult. lb./sq. in |
| | | 2.04 | 1.98 | 3.08 | 6.28 | 230 | 36.62 | 16800 | 28300 | 5454 | 9188 |
| A | | 1.99 | 1.98 | 3.08 | 6.15 | 226 | 36.86 | 17500 | 27550 | 5682 | 8845 |
| Avr. | | | | | | | | 17150 | 27925 | 5568 | 9066 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 239 | 38.05 | 21000 | 25070 | 6688 | 7984 |
| B | | 2.00 | 2.00 | 3.14 | 6.28 | 238 | 37.89 | 16000 | 24800 | 5095 | 7898 |
| | | 2.03 | 2.00 | 3.14 | 6.37 | 237 | 37.25 | 20000 | 28760 | 6369 | 9159 |
| Avr. | | | | | | | | 19000 | 26210 | 6050 | 8347 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 239 | 38.05 | 19800 | 21850 | 6306 | 6944 |
| C | | 2.00 | 1.90 | 3.08 | 6.75 | 229 | 37.17 | 20800 | 25440 | 6753 | 8259 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 240 | 38.21 | 11500 | 23040 | 3667 | 7337 |
| Avr. | | | | | | | | 17333 | 23443 | 5574 | 7513 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 236 | 37.58 | 5200 | 12070 | 1656 | 38441 |
| $A_{10}$ | | 2.01 | 2.00 | 3.14 | 6.31 | 237 | 37.56 | 7000 | 17620 | 2229 | 5611 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 235 | 37.42 | 7100 | 16470 | 2261 | 5245 |
| Avr. | | | | | | | | 6433 | 15386 | 2049 | 4900 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 230 | 36.62 | 13020 | 25000 | 4146 | 7961 |
| $B_{10}$ | | 2.00 | 1.96 | 3.02 | *.04 | 216 | 35.76 | 10500 | 24150 | 3476 | 7996 |
| | | 2.00 | 1.97 | 3.05 | 6.10 | 217 | 35.57 | 12500 | 25360 | 4098 | 8314 |
| Avr. | | | | | | | | 12340 | 24837 | 3907 | 8090 |
| | | 2.05 | 2.01 | 3.17 | 6.50 | 240 | 36.92 | 17000 | 17800 | 5362 | 5615 |
| $C_{10}$ | | 2.05 | 2.05 | 3.30 | 6.77 | 241 | 35.59 | 13400 | 16885 | 4060 | 5117 |
| | | 2.03 | 2.04 | 3.27 | 6.64 | 243 | 36.60 | 6400 | 21470 | 1954 | 6565 |
| Avr. | | | | | | | | 12133 | 18718 | 3792 | 5766 |
| | | 2.07 | 2.00 | 3.14 | 6.50 | 239 | 36.77 | 17500 | 25570 | 5573 | 8143 |
| $A_{20}$ | | 2.06 | 2.01 | 3.17 | 6.53 | 238 | 36.44 | 11000 | 23010 | 3470 | 7258 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 221 | 35.19 | 16420 | 27910 | 5229 | 8888 |
| Avr. | | | | | | | | 14973 | 25496 | 4757 | 8096 |
| | | 2.06 | 2.04 | 3.27 | 6.74 | 233 | 34.57 | 13000 | 21150 | 3975 | 6464 |
| $B_{20}$ | | 2.04 | 2.03 | 3.24 | 6.61 | 232 | 35.09 | 11000 | 16740 | 3395 | 5166 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 220 | 35.03 | 9200 | 13030 | 2929 | 4149 |
| Avr. | | | | | | | | 11067 | 16973 | 3433 | 5259 |
| | | 1.98 | 2.00 | 3.14 | 6.22 | 220 | 35.38 | 17200 | 21680 | 5477 | 6904 |
| $C_{20}$ | | 2.00 | 2.00 | 3.14 | 6.28 | 235 | 37.40 | 13800 | 20390 | 3494 | 6493 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 200 | 31.80 | 26760 | 26760 | 8522 | 8522 |
| Avr. | | | | | | | | 19253 | 22943 | 5831 | 7306 |
| | | 2.04 | 2.00 | 3.14 | 6.41 | 235 | 36.65 | 17000 | 27090 | 5414 | 8624 |
| $A_{30}$ | | 2.04 | 2.00 | 3.14 | 6.41 | 234 | 36.48 | 5200 | 16220 | 1656 | 5665 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 232 | 36.95 | 15070 | 23180 | 4799 | 7382 |
| Avr. | | | | | | | | 12423 | 22163 | 3956 | 7057 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 229 | 36.48 | 22000 | 26470 | 7006 | 8429 |
| $B_{30}$ | | 2.00 | 2.00 | 3.14 | 6.28 | 232 | 36.96 | 9500 | 15440 | 3025 | 4914 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 219 | 34.90 | 17100 | 19310 | 5445 | 6149 |
| Avr. | | | | | | | | 16200 | 20406 | 5159 | 6497 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 224 | 35.64 | 23370 | 23370 | 7442 | 7442 |
| $C_{30}$ | | 2.05 | 2.04 | 3.27 | 6.70 | 240 | 35.80 | 27500 | 28600 | 8409 | 8746 |
| | | 2.04 | 2.00 | 3.14 | 6.41 | 227 | 35.40 | 19200 | 25320 | 6114 | 8063 |
| Avr. | | | | | | | | 20023 | 25763 | 7322 | 8083 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 217 | 34.59 | 10000 | 14180 | 3184 | 4516 |
| $A_{40}$ | | 2.00 | 2.00 | 3.14 | 6.28 | 207 | 32.97 | 12000 | 15110 | 3821 | 4812 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 232 | 36.95 | 18000 | 20000 | 5732 | 6369 |
| Avr. | | | | | | | | 13333 | 16430 | 4245 | 5232 |
| | | 2.01 | 1.98 | 3.08 | 6.19 | 222 | 35.87 | 18000 | 18000 | 5843 | 5843 |
| $B_{40}$ | | 2.00 | 2.00 | 3.14 | 6.28 | 220 | 35.00 | 12000 | 14000 | 3821 | 4458 |
| | | 2.00 | 1.99 | 3.11 | 6.22 | 219 | 35.20 | 23070 | 23070 | 7418 | 7418 |
| Avr. | | | | | | | | 17690 | 18357 | 5694 | 5906 |
| | | 2.00 | 2.00 | 3.14 | 6.27 | 225 | 35.90 | 17000 | 18310 | 5412 | 5828 |
| $C_{40}$ | | 2.00 | 1.99 | 3.11 | 6.22 | 224 | 36.00 | 10100 | 16310 | 3246 | 5240 |
| | | 2.00 | 1.98 | 3.08 | 6.16 | 224 | 36.36 | 15500 | 19670 | 5030 | 6380 |
| Avr. | | | | | | | | 14200 | 18097 | 4563 | 5816 |
| Average of Averages | | | | | | | | | | | |
| A - B & C | | | | | | | | | | 5731 | 8309 |
| $A_{10}$ - $B_{10}$ & $C_{10}$ | | | | | | | | | | 3249 | 6252 |
| $A_{20}$ - $B_{20}$ & $C_{20}$ | | | | | | | | | | 4674 | 6887 |
| $A_{30}$ - $B_{30}$ & $C_{30}$ | | | | | | | | | | 5479 | 7212 |
| $A_{40}$ - $B_{40}$ & $C_{40}$ | | | | | | | | | | 4834 | 5650 |
| Average of highest breaks | | | | | | | | | | | |
| A - B & C | | | | | | | | | | 6374 | 8869 |
| $A_{10}$ - $B_{10}$ & $C_{10}$ | | | | | | | | | | 3923 | 6691 |
| $A_{20}$ - $B_{20}$ & $C_{20}$ | | | | | | | | | | 6023 | 7958 |
| $A_{30}$ - $B_{30}$ & $C_{30}$ | | | | | | | | | | 6943 | 8600 |
| $A_{40}$ - $B_{40}$ & $C_{40}$ | | | | | | | | | | 6187 | 6722 |

# RESULTS OF COMPRESSION TESTS

(Mortar Specimens)

**Tested at age of 28 days**

| Series No. | Spec'c made 1916 Date | Dim'nsions | | | | Weight | | Load | | Stress | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Height inches | Diam. inches | Area in Sq. in. | Vol. in Cu. in. | Total Gms. | Unit Gms. | 1st Cr. lbs. | Ult. lbs. | 1st Cr. lb./sq. in | Ult. lb./sq. in |
| | | 2.05 | 2.06 | 3.33 | 6.83 | 2.58 | 37.77 | 13060 | 13060 | 3920 | 3920 |
| A | 2-23 | 2.03 | 2.00 | 3.14 | 6.37 | 239 | 37.52 | 10560 | 10560 | 3360 | 3360 |
| | | 2.02 | 1.99 | 3.11 | 6.28 | 244 | 38.86 | 11240 | 11240 | 3620 | 3620 |
| Avr. | | | | | | | | 11620 | 11620 | 3633 | 3633 |
| | | 2.06 | 2.02 | 3.20 | 6.59 | 252 | 38.21 | 10240 | 10240 | 3200 | 3200 |
| B | 2-23 | 2.10 | 2.02 | 3.20 | 6.72 | 256 | 38.10 | 10830 | 10830 | 3390 | 3390 |
| | | 2.08 | 2.03 | 3.23 | 6.73 | 257 | 38.2 | 11970 | 11970 | 3700 | 3700 |
| Avr. | | | | | | | | 11013 | 11013 | 3430 | 3430 |
| | | 2.10 | 2.02 | 3.20 | 6.72 | 258 | 38.4 | 12990 | 12990 | 4060 | 4060 |
| C | 2-26 | 2.10 | 2.04 | 3.27 | 6.87 | 260 | 37.81 | 12540 | 12540 | 3920 | 3920 |
| | | 2.09 | 2.01 | 3.17 | 6.62 | 254 | 38.38 | 11200 | 11200 | 3540 | 3540 |
| Avr. | | | | | | | | 12243 | 12243 | 3840 | 3840 |
| | | 2.08 | 2.00 | 3.14 | 6.53 | 240 | 36.76 | 9450 | 9450 | 3010 | 3010 |
| $A_{10}$ | 2-26 | 2.10 | 2.02 | 3.20 | 6.72 | 256 | 38.1 | 10960 | 10960 | 3420 | 3420 |
| | | 2.09 | 2.02 | 3.20 | 6.68 | 254 | 38.04 | 11400 | 11400 | 3560 | 3560 |
| Avr. | | | | | | | | 10603 | 10603 | 3330 | 3330 |
| | | 2.05 | 2.00 | 3.14 | 6.44 | 235 | 36.5 | 7000 | 8500 | 2220 | 2700 |
| $B_{10}$ | 2-26 | 2.04 | 1.99 | 3.11 | 6.35 | 233 | 36.7 | 9020 | 9020 | 2900 | 2900 |
| | | 2.05 | 2.04 | 3.27 | 6.70 | 247 | 36.88 | 9400 | 9400 | 2870 | 2870 |
| Avr. | | | | | | | | 8473 | 8773 | 2663 | 2823 |
| | | 2.10 | 2.02 | 3.20 | 6.72 | 251 | 37.38 | 8520 | 8520 | 2660 | 2660 |
| $C_{10}$ | 2-26 | 2.07 | 1.98 | 3.08 | 6.38 | 239 | 37.47 | 10210 | 10210 | 3320 | 3320 |
| | | 2.06 | 1.98 | 3.08 | 6.35 | 251 | 39.52 | 7710 | 7710 | 2500 | 2500 |
| Avr. | | | | | | | | 8813 | 8813 | 2827 | 2827 |
| | | 2.05 | 2.00 | 3.14 | 6.44 | 246 | 38.2 | 11000 | 12010 | 3500 | 3830 |
| $A_{20}$ | 2-28 | 2.04 | 1.97 | 3.05 | 6.23 | 242 | 38.86 | 9000 | 9000 | 2950 | 2950 |
| | | 2.05 | 1.98 | 3.08 | 6.32 | 243 | 38.46 | 8690 | 8690 | 2850 | 2850 |
| Avr. | | | | | | | | 9563 | 9900 | 3100 | 3210 |
| | | 2.10 | 2.01 | 3.17 | 6.65 | 252 | 37.9 | 9650 | 9650 | 3040 | 3040 |
| $B_{20}$ | 2-28 | 2.07 | 2.03 | 3.28 | 6.69 | 252 | 37.66 | 8900 | 8900 | 2750 | 2750 |
| | | 2.07 | 1.97 | 3.05 | 6.32 | 237 | 37.5 | 8000 | 8000 | 2620 | 2620 |
| Avr. | | | | | | | | 8850 | 8850 | 2803 | 2803 |
| | | 2.06 | 2.03 | 3.23 | 6.66 | 249 | 37.39 | | | | |
| $C_{20}$ | 2-28 | 2.06 | 1.98 | 3.08 | 6.35 | 241 | 37.98 | 5740 | 5740 | 1860 | 1860 |
| | | 2.05 | 2.03 | 3.23 | 6.62 | 236 | 35.64 | 5720 | 8380 | 1770 | 2590 |
| Avr. | | | | | | | | 5720 | 8380 | 1770 | 2590 |
| | | 2.09 | 1.98 | 3.08 | 6.44 | 236 | 36.62 | 7710 | 7710 | 2500 | 2500 |
| $A_{30}$ | 3-1 | 2.09 | 2.03 | 3.23 | 6.75 | 254 | 37.65 | 5520 | 5520 | 1710 | 1710 |
| | | 2.10 | 2.10 | 3.45 | 7.27 | 243 | 33.42 | 6550 | 6550 | 1890 | 1890 |
| Avr. | | | | | | | | 6593 | 6593 | 2033 | 2033 |
| | | 2.10 | 1.98 | 3.08 | 6.47 | 241 | 37.28 | 7230 | 7230 | 2340 | 2340 |
| $B_{30}$ | 3-1 | 2.10 | 2.00 | 3.14 | 6.60 | 251 | 38.04 | 7220 | 7220 | 2300 | 2300 |
| | | 2.12 | 2.02 | 3.20 | 6.78 | 254 | 37.48 | 6560 | 6560 | 2050 | 2060 |
| Avr. | | | | | | | | 7003 | 7003 | 2230 | 2230 |
| | | 2.10 | 2.02 | 3.20 | 6.72 | 254 | 37.78 | 4950 | 4950 | 1550 | 1550 |
| $C_{30}$ | 3-1 | 2.08 | 1.99 | 3.11 | 6.47 | 237 | 36.62 | 6030 | 6030 | 1940 | 1940 |
| | | 2.12 | 2.00 | 3.14 | 6.65 | 254 | 38.18 | 3930 | 3930 | 1250 | 1250 |
| Avr. | | | | | | | | 4970 | 4970 | 1580 | 1580 |
| | | 2.08 | 1.99 | 3.11 | 6.47 | 240 | 37.10 | 5090 | 5090 | 1640 | 1640 |
| $A_{40}$ | 3-3 | 2.06 | 1.97 | 3.05 | 6.29 | 236 | 37.56 | 4760 | 4760 | 1560 | 1560 |
| | | 2.12 | 2.02 | 3.20 | 6.78 | 252 | 37.16 | 7420 | 7420 | 2320 | 2320 |
| Avr. | | | | | | | | 5760 | 5760 | 1840 | 1840 |
| | | 2.06 | 2.02 | 3.20 | 6.59 | 251 | 38.1 | 6100 | 6100 | 1900 | 1900 |
| $D_{40}$ | 3-3 | 2.04 | 2.00 | 3.14 | 6.41 | 237 | 36.98 | 5520 | 5520 | 1760 | 1760 |
| | | 2.06 | 2.02 | 3.20 | 6.59 | 248 | 37.62 | 6550 | 6550 | 2040 | 2040 |
| Avr. | | | | | | | | 6057 | 6057 | 1900 | 1900 |
| | | 2.08 | 2.02 | 3.20 | 6.66 | 247 | 37.1 | 3300 | 3300 | 1030 | 1030 |
| $C_{40}$ | 3-3 | 2.08 | 2.03 | 3.23 | 6.73 | 250 | 37.16 | 5870 | 5870 | 1820 | 1820 |
| | | 2.05 | 1.98 | 3.08 | 6.32 | 234 | 37.02 | 4820 | 4820 | 1560 | 1560 |
| Avr. | | | | | | | | 4663 | 4663 | 1470 | 1470 |
| Average of Averages | | | | | | | | | | | |
| A - B - C | | | | | | | | | | 3634 | 3634 |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | | | | | | | | | 2940 | 2993 |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | | | | | | | | | 2558 | 2868 |
| $A_{30}$ - $B_{30}$ - $C_{30}$ | | | | | | | | | | 1944 | 1944 |
| $A_{40}$ - $B_{40}$ - $C_{40}$ | | | | | | | | | | 1737 | 1737 |
| Average of Highest Breaks | | | | | | | | | | | |
| A - B - C | | | | | | | | | | 3890 | 3890 |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | | | | | | | | | 3260 | 3260 |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | | | | | | | | | 2770 | 3150 |
| $A_{30}$ - $B_{30}$ - $C_{30}$ | | | | | | | | | | 2260 | 2260 |
| $A_{40}$ - $B_{40}$ - $C_{40}$ | | | | | | | | | | 2060 | 2060 |

# RESULTS OF COMPRESSION TESTS

(Mortar Specimens)

**Tested at age of 12 weeks**

| Series No. | Spec'c made 1916 Date | Dim'nsions: Height inches | Dim'nsions: Diam. inches | Area in Sq. in. | Vol. in Cu. in. | Weight: Total Gms. | Weight: Unit Gms. | Load: 1st Cr. lbs. | Load: Ult. lbs. | Stress: 1st Cr. lb./sq. in | Stress: Ult. lb./sq. in |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2.10 | 2.05 | 3.30 | 6.93 | 257 | 37.10 | 17220 | 17220 | 5220 | 5220 |
| A | 2-23 | 2.08 | 1.95 | 2.98 | 6.20 | 237 | 38.23 | 13510 | 13510 | 4540 | 4540 |
| | | 2.11 | 2.02 | 3.20 | 6.75 | 256 | 37.92 | 16540 | 16540 | 5170 | 5170 |
| Avr. | | | | | | | | 15757 | 15757 | 4980 | 4980 |
| | | 2.07 | 2.02 | 3.20 | 6.62 | 254 | 38.37 | 12080 | 12080 | 3780 | 3780 |
| B | 2-23 | 2.10 | 2.01 | 3.17 | 6.66 | 251 | 37.70 | 12810 | 12810 | 4040 | 4040 |
| | | 2.10 | 2.04 | 3.27 | 6.87 | 258 | 37.56 | 10600 | 10600 | 3380 | 3380 |
| Avr. | | | | | | | | 11830 | 11830 | 3730 | 3730 |
| | | 2.08 | 1.98 | 3.11 | 6.47 | 247 | 38.19 | 14690 | 14690 | 4720 | 4720 |
| C | 2-26 | 2.10 | 2.02 | 3.20 | 6.72 | 255 | 37.94 | 14980 | 14980 | 4680 | 4680 |
| | | 2.13 | 2.00 | 3.14 | 6.68 | 262 | 39.23 | 16000 | 16000 | 5100 | 5100 |
| Avr. | | | | | | | | 15223 | 15223 | 4830 | 4830 |
| | | 2.02 | 2.01 | 3.17 | 6.41 | 240 | 37.44 | 8190 | 8190 | 2580 | 2580 |
| $A_{10}$ | 2-26 | 2.03 | 2.00 | 3.14 | 6.38 | 239 | 37.46 | 14560 | 14560 | 4630 | 4630 |
| | | 2.02 | 1.98 | 3.08 | 6.28 | 235 | 37.42 | 11460 | 11460 | 3720 | 3720 |
| Avr. | | | | | | | | 11400 | 11400 | 3640 | 3640 |
| | | 2.04 | 2.04 | 3.27 | 6.67 | 247 | 37.06 | 11730 | 11730 | 3590 | 3590 |
| $B_{10}$ | 2-26 | 2.02 | 1.97 | 3.05 | 6.16 | 236 | 38.30 | 15420 | 15420 | 5070 | 5070 |
| | | 2.03 | 2.04 | 3.27 | 6.64 | 247 | 37.23 | 12070 | 12070 | 3690 | 3640 |
| Avr. | | | | | | | | 13073 | 13073 | 4120 | 4120 |
| | | 2.11 | 2.02 | 3.20 | 6.75 | 254 | 37.83 | 12810 | 12810 | 4010 | 4010 |
| | 2-26 | 2.10 | 2.02 | 3.20 | 6.72 | 253 | 37.64 | 8690 | 8690 | 2710 | 2710 |
| | | 2.10 | 2.02 | 3.20 | 6.72 | 252 | 37.51 | 10310 | 10310 | 3230 | 3220 |
| Avr. | | | | | | | 37.51 | 10603 | 10603 | 3310 | 3310 |
| $A_{20}$ | 2-28 | 2.09 | 1.99 | 3.11 | 6.50 | 242 | 37.22 | 13300 | 13300 | 4280 | 4280 |
| | | 2.08 | 1.99 | 3.11 | 6.47 | 242 | 37.41 | 11640 | 11640 | 3740 | 3740 |
| Avr. | | | | | | | | 12897 | 12897 | 4110 | 4110 |
| | | 2.10 | 2.03 | 3.23 | 6.78 | 258 | 38.08 | 10740 | 10740 | 3330 | 3330 |
| $B_{20}$ | 2-28 | 2.07 | 1.98 | 3.08 | 6.38 | 237 | 37.16 | 10560 | 10560 | 3430 | 3430 |
| | | 2.10 | 2.02 | 3.20 | 6.72 | 255 | 37.64 | 10310 | 10310 | 3220 | 3220 |
| Avr. | | | | | | | | 10537 | 10537 | 3330 | 3330 |
| | | 2.05 | 2.00 | 3.14 | 6.44 | 238 | 36.96 | 10030 | 10030 | 3200 | 3200 |
| $C_{20}$ | 2-28 | 2.10 | 2.02 | 3.20 | 6.72 | 253 | 37.64 | 10080 | 10080 | 3150 | 3150 |
| | | 2.06 | 1.98 | 3.08 | 6.35 | 240 | 37.80 | 9920 | 9920 | 3220 | 3220 |
| Avr. | | | | | | | | 10010 | 10010 | 3190 | 3190 |
| | | 2.08 | 2.00 | 3.14 | 6.53 | 240 | 36.77 | 9270 | 9270 | 2950 | 2950 |
| $A_{30}$ | 3-1 | 2.12 | 2.04 | 3.27 | 6.93 | 255 | 36.82 | 10930 | 10930 | 3350 | 3350 |
| | | 2.04 | 2.00 | 3.14 | 6.41 | 256 | 39.94 | 9780 | 9780 | 3110 | 3110 |
| Avr. | | | | | | | | 9993 | 9993 | 3140 | 3140 |
| | | 2.10 | 2.00 | 3.14 | 6.60 | 252 | 38.17 | 8960 | 8960 | 2850 | 2850 |
| $B_{30}$ | 3-1 | 2.08 | 1.99 | 3.11 | 6.47 | 241 | 37.26 | 11180 | 11180 | 3590 | 3590 |
| | | 2.08 | 1.99 | 3.11 | 6.47 | 240 | 37.08 | 9490 | 9490 | 3050 | 3050 |
| Avr. | | | | | | | | 9877 | 9877 | 3160 | 3160 |
| | | 2.08 | 1.98 | 3.08 | 6.41 | 236 | 36.82 | 9920 | 9920 | 3220 | 3220 |
| $C_{30}$ | 3-1 | 2.07 | 1.98 | 3.08 | 6.38 | 239 | 37.46 | 9930 | 9930 | 3220 | 3220 |
| | | 2.10 | 2.02 | 3.20 | 6.72 | 254 | 37.79 | 9370 | 9370 | 2930 | 2930 |
| Avr. | | | | | | | | 9740 | 9740 | 3120 | 3120 |
| | | 2.10 | 1.98 | 3.08 | 6.47 | 237 | 36.64 | 6990 | 6990 | 2270 | 2270 |
| $A_{40}$ | 3-3 | 2.10 | 2.02 | 3.20 | 6.72 | 249 | 37.04 | 9500 | 9500 | 2970 | 2970 |
| | | 2.10 | 2.00 | 3.14 | 6.60 | 248 | 37.58 | 9820 | 9820 | 3120 | 3120 |
| Avr. | | | | | | | | 8770 | 8770 | 2790 | 2790 |
| | | 2.10 | 2.00 | 3.14 | 6.60 | 240 | 36.38 | 5960 | 5960 | 1900 | 1900 |
| $B_{40}$ | 3-3 | 2.08 | 2.00 | 3.14 | 6.53 | 243 | 37.23 | 6560 | 6560 | 2090 | 2090 |
| | | 2.08 | 2.00 | 3.14 | 6.53 | 241 | 36.92 | 7110 | 7110 | 2260 | 2260 |
| Avr. | | | | | | | | 6543 | 6543 | 2080 | 2080 |
| | | 2.10 | 2.00 | 3.14 | 6.60 | 237 | 35.98 | 7870 | 7870 | 2500 | 2500 |
| $C_{40}$ | 3-3 | 2.05 | 1.98 | 3.08 | 6.32 | 236 | 37.39 | 9040 | 9040 | 2930 | 2930 |
| | | 2.05 | 1.98 | 3.08 | 6.32 | 232 | 36.70 | 5770 | 5770 | 1870 | 1870 |
| Avr. | | | | | | | | 7560 | 7560 | 2433 | 2433 |
| Average of Averages | | | | | | | | | | | |
| A - B - C | | | | | | | | | | 4510 | 4510 |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | | | | | | | | | 3690 | 3690 |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | | | | | | | | | 3540 | 3540 |
| $A_{30}$ - $B_{30}$ - $C_{30}$ | | | | | | | | | | 3140 | 3140 |
| $A_{40}$ - $B_{40}$ - $C_{40}$ | | | | | | | | | | 2101 | 2101 |
| Average of Highest Breaks | | | | | | | | | | | |
| A - B - C | | | | | | | | | | 4790 | 4790 |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | | | | | | | | | 4570 | 4570 |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | | | | | | | | | 3660 | 3660 |
| $A_{30}$ - $B_{30}$ - $C_{30}$ | | | | | | | | | | 3390 | 3390 |
| $A_{40}$ - $B_{40}$ - $C_{40}$ | | | | | | | | | | 2770 | 2770 |

## RESULTS OF COMPRESSION TESTS

### Tested at age of 24 weeks

(Mortar Specimens)

| Series No. | Spec'c made 1916 Date | Dim'nsions: Height inches | Dim'nsions: Diam. inches | Area in Sq. in. | Vol. in Cu. in. | Weight: Total Gms. | Weight: Unit Gms. | Load: 1st Cr. lbs. | Load: Ult. lbs. | Stress: 1st Cr. lb./sq. in | Stress: Ult. lb./sq. in |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2.11 | 2.01 | 3.17 | 6.69 | 258 | 38.57 | 13730 | 15890 | 4330 | 5020 |
| A | 2-23 | 2.08 | 2.04 | 3.27 | 6.80 | 257 | 37.83 | 10290 | 11060 | 3150 | 3380 |
| | | 2.12 | 2.01 | 3.17 | 6.72 | 259 | 38.52 | | 12710 | | 4020 |
| Avr. | | | | | | | | 12010 | 13220 | 3740 | 4140 |
| | | 2.12 | 2.03 | 3.23 | 6.85 | 254 | 37.08 | 13480 | 13480 | 4180 | 4180 |
| B | 2-23 | 2.10 | 2.04 | 3.27 | 6.87 | 252 | 36.66 | | 17280 | | 5500 |
| | | 2.08 | 1.97 | 3.05 | 6.35 | 249 | 29.22 | 11280 | 11770 | 3700 | 3860 |
| Avr. | | | | | | | | 13480 | 15380 | 4180 | 4840 |
| | | 2.11 | 2.00 | 3.14 | 6.63 | 247 | 37.24 | 13180 | 13180 | 4200 | 4200 |
| C | 2-26 | 2.09 | 2.00 | 3.14 | 6.57 | 244 | 37.16 | 11150 | 11150 | 3550 | 3550 |
| | | 2.11 | 2.02 | 3.20 | 6.75 | 256 | 37.94 | | 13490 | | 4220 |
| Avr. | | | | | | | | 12165 | 12607 | 3870 | 3990 |
| | | 2.06 | 1.98 | 3.08 | 6.35 | 236 | 37.20 | 12370 | 12370 | 4020 | 4020 |
| $A_{10}$ | 2-26 | 2.12 | 2.02 | 3.20 | 6.78 | 255 | 37.60 | 14410 | 14410 | 4510 | 4510 |
| | | 2.12 | 2.03 | 3.23 | 6.85 | 256 | 37.39 | 14630 | 14630 | 4530 | 4530 |
| Avr. | | | | | | | | 13803 | 13803 | 4350 | 4350 |
| | | 2.10 | 2.00 | 3.14 | 6.60 | 245 | 37.10 | 14000 | 14000 | 4460 | 4460 |
| $B_{10}$ | 2-26 | 2.07 | 2.05 | 3.30 | 6.83 | 249 | 36.48 | 9390 | 9390 | 2840 | 2840 |
| | | 2.06 | 2.05 | 3.30 | 6.80 | 246 | 36.18 | 14010 | 14010 | 4250 | 4250 |
| Avr. | | | | | | | | 12467 | 12467 | 3850 | 3850 |
| Avr. | | 2.10 | 2.03 | 3.23 | 6.78 | 262 | 37.14 | 8340 | 8340 | 2580 | 2580 |
| $C_{10}$ | 2-26 | 2.11 | 2.04 | 3.27 | 6.90 | 252 | 36.52 | 15230 | 15230 | 4660 | 4660 |
| | | 2.10 | 1.99 | 3.11 | 6.54 | 241 | 36.87 | 13380 | 13380 | 4310 | 4310 |
| Avr. | | | | | | | | 12317 | 12317 | 3850 | 3850 |
| | | 2.11 | 2.05 | 3.30 | 6.96 | 257 | 36.94 | 13660 | 13660 | 4140 | 4140 |
| $A_{20}$ | 2-28 | 2.07 | 2.00 | 3.14 | 6.50 | 242 | 37.24 | 12160 | 12160 | 3870 | 3870 |
| | | 2.10 | 2.00 | 3.14 | 6.60 | 242 | 36.70 | 8310 | 8750 | 2640 | 2780 |
| Avr. | | | | | | | | 11377 | 11523 | 3550 | 3690 |
| | | 2.09 | 2.00 | 3.14 | 6.57 | 240 | 36.53 | 9080 | 9080 | 2890 | 2890 |
| $B_{20}$ | 2-28 | 2.12 | 2.02 | 3.20 | 6.78 | 253 | 37.30 | 7810 | 8170 | 2440 | 2550 |
| | | 2.11 | 2.05 | 3.30 | 6.96 | 255 | 36.66 | 10020 | 10020 | 3040 | 3040 |
| Avr. | | | | | | | | 8970 | 9090 | 2790 | 2830 |
| | | 2.08 | 1.99 | 3.11 | 6.48 | 237 | 36.58 | 8100 | 8100 | 2600 | 2600 |
| $C_{20}$ | 2-28 | 2.07 | 1.99 | 3.11 | 6.45 | 238 | 36.90 | 4200 | 6410 | 1350 | 2060 |
| | | 2.08 | 2.05 | 3.30 | 6.87 | 252 | 36.66 | 9120 | 9120 | 2760 | 2760 |
| Avr. | | | | | | | | 7140 | 7877 | 2240 | 2470 |
| | | 2.08 | 2.05 | 3.30 | 6.87 | 255 | 37.12 | 10530 | 11690 | 3190 | 3540 |
| $A_{30}$ | 3-1 | 2.07 | 2.02 | 3.20 | 6.63 | 242 | 36.50 | 6560 | 7700 | 2040 | 2400 |
| | | 2.10 | 2.04 | 3.27 | 6.87 | 256 | 37.30 | 10540 | 10540 | 3230 | 3230 |
| Avr. | | | | | | | | 9210 | 9977 | 2820 | 3060 |
| | | 2.00 | 1.99 | 3.11 | 6.22 | 216 | 34.72 | 5650 | 7820 | 1820 | 2510 |
| $B_{30}$ | 3-1 | 2.11 | 2.02 | 3.20 | 6.75 | 251 | 37.20 | 8090 | 8090 | 2590 | 2530 |
| | | 2.12 | 2.04 | 3.27 | 6.93 | 253 | 36.52 | 12560 | 12560 | 3840 | 3840 |
| Avr. | | | | | | | | 10325 | 10325 | 3250 | 3250 |
| | | 2.11 | 2.02 | 3.20 | 6.75 | 254 | 37.66 | 12070 | 12070 | 3770 | 3770 |
| $C_{30}$ | 3-1 | 2.09 | 1.97 | 3.05 | 6.38 | 237 | 37.14 | 6380 | 7500 | 2090 | 2450 |
| | | 2.10 | 2.00 | 3.14 | 6.60 | 248 | 37.58 | 10690 | 10690 | 3490 | 3490 |
| Avr. | | | | | | | | 9713 | 10087 | 3120 | 3240 |
| | | 2.12 | 2.01 | 3.17 | 6.72 | 244 | 36.32 | 5260 | 5560 | 1660 | 1750 |
| $A_{40}$ | 3-3 | 2.09 | 2.00 | 3.14 | 6.57 | 235 | 35.77 | 8910 | 8910 | 2840 | 2840 |
| | | 2.11 | 2.04 | 3.27 | 6.90 | 252 | 36.52 | 9750 | 9750 | 2980 | 2980 |
| Avr. | | | | | | | | 7973 | 8073 | 2490 | 2520 |
| | | 2.13 | 2.00 | 3.14 | 6.69 | 242 | 36.18 | 9220 | 9220 | 2930 | 2930 |
| $B_{40}$ | 313 | 2.14 | 2.04 | 3.27 | 6.72 | 255 | 37.96 | 7430 | 7430 | 2270 | 2270 |
| | | 2.14 | 2.00 | 3.14 | 6.72 | 242 | 36.00 | 6420 | 6420 | 2040 | 2040 |
| Avr. | | | | | | | | 7690 | 7690 | 2410 | 2410 |
| | | 2.14 | 2.03 | 3.23 | 6.92 | 255 | 36.88 | 7500 | 7500 | 2320 | 2320 |
| $C_{40}$ | 3-3 | 2.11 | 2.04 | 3.27 | 6.90 | 251 | 36.40 | 6570 | 6570 | 2010 | 2010 |
| | | 2.12 | 2.04 | 3.27 | 6.93 | 254 | 36.66 | 6660 | 6660 | 2040 | 2040 |
| Avr. | | | | | | | | 6660 | 6660 | 2040 | 2040 |
| Average of Averages | | | | | | | | | | | |
| A - B - C | | | | | | | | | | 3930 | 4320 |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | | | | | | | | | 4020 | 4020 |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | | | | | | | | | 2860 | 2970 |
| $A_{30}$ - $B_{30}$ - $C_{30}$ | | | | | | | | | | 3060 | 3180 |
| $A_{40}$ - $B_{40}$ - $C_{40}$ | | | | | | | | | | 2310 | 2320 |
| Average of Highest Breaks | | | | | | | | | | | |
| A - B - C | | | | | | | | | | 4240 | 4910 |
| $A_{10}$ - $B_{10}$ - $C_{10}$ | | | | | | | | | | 4550 | 4550 |
| $A_{20}$ - $B_{20}$ - $C_{20}$ | | | | | | | | | | 3310 | 3310 |
| $A_{30}$ - $B_{30}$ - $C_{30}$ | | | | | | | | | | 3610 | 3720 |
| $A_{40}$ - $B_{40}$ - $C_{40}$ | | | | | | | | | | 2270 | 2740 |

# RESULTS OF COMPRESSION TESTS

(Mortar Specimens)

## Tested at age of 52 weeks

| Series No. | Spec'c made Date | Dim'nsions Height inches | Diam. inches | Area in inches | Vol. in inches | Weight Total Gms. | Unit Gms. | Load 1st Cr. lbs. | Ult. lbs. | Stress 1st Cr. lb./sq. in. | Ult. lb./sq. in. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2.05 | 2.05 | 3.30 | 6.77 | 258 | 38.1 | 12570 | 12570 | 3809 | 3809 |
| A | | 2.05 | 2.00 | 3.14 | 6.44 | 241 | 37.4 | 10380 | 10380 | 3304 | 3304 |
| | | 2.07 | 2.00 | 3.14 | 6.50 | 260 | 40.0 | 15890 | 15890 | 5056 | 5056 |
| Avr. | | | | | | | | 12946 | 12946 | 4058 | 4056 |
| | | 2.05 | 2.00 | 3.14 | 6.44 | 244 | 37.9 | 12110 | 12110 | 3859 | 3859 |
| B | | 2.04 | 2.00 | 3.14 | 6.41 | 238 | 37.1 | 11000 | 13000 | 3502 | 4140 |
| | | 2.03 | 2.00 | 3.14 | 6.37 | 237 | 37.2 | 8000 | 10210 | 2547 | 3252 |
| Avr. | | | | | | | | 10370 | 11773 | 3303 | 3750 |
| | | 2.04 | 2.00 | 3.14 | 6.41 | 246 | 38.4 | 12000 | 13650 | 3822 | 4350 |
| C | | 2.04 | 2.00 | 3.14 | 6.41 | 245 | 38.2 | 10000 | 11850 | 3180 | 3772 |
| | | 2.02 | 2.02 | 3.21 | 6.48 | 248 | 38.3 | 15000 | 15770 | 4672 | 4912 |
| Avr. | | | | | | | | 12333 | 13757 | 4225 | 4345 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 257 | 40.9 | 11500 | 11890 | 3660 | 3782 |
| $A_{10}$ | | 2.04 | 2.00 | 3.14 | 6.41 | 239 | 37.3 | 11550 | 11550 | 3678 | 3679 |
| | | 2.00 | 2.00 | 3.14 | 6.28 | 260 | 41.4 | 12000 | 12000 | 3821 | 3820 |
| Avr. | | | | | | | | 11683 | 11813 | 3720 | 3760 |
| | | 2.08 | 2.00 | 3.14 | 6.53 | 246 | 37.7 | 13000 | 13600 | 4138 | 4331 |
| $B_{10}$ | | 2.05 | 2.02 | 3.21 | 6.58 | 248 | 37.7 | 10600 | 16080 | 3300 | 3327 |
| | | 2.00 | 1.93 | 2.93 | 5.86 | 238 | 40.7 | 14500 | 14500 | 4950 | 4948 |
| Avr. | | | | | | | | 12700 | 12927 | 4129 | 4202 |
| | | 2.10 | 2.00 | 3.14 | 6.59 | 256 | 38.9 | 9506 | 9500 | 3240 | 3025 |
| $C_{10}$ | | 2.06 | 2.00 | 3.14 | 6.47 | 256 | 39.6 | 14200 | 14250 | 4540 | 4537 |
| | | 2.05 | 2.00 | 3.14 | 6.43 | 242 | 37.6 | 10800 | 10800 | 3440 | 3440 |
| Avr. | | | | | | | | 11500 | 11517 | 3740 | 3667 |
| | | 2.12 | 2.00 | 3.14 | 6.66 | 256 | 38.4 | 8000 | 11970 | 2548 | 3812 |
| $A_{20}$ | | 2.12 | 2.00 | 3.14 | 6.66 | 255 | 38.3 | 12860 | 12860 | 4068 | 4069 |
| | | 2.04 | 2.04 | 3.27 | 6.67 | 259 | 38.8 | 13000 | 14120 | 3976 | 4320 |
| Avr. | | | | | | | | 11287 | 12983 | 3531 | 4067 |
| | | 2.05 | 2.00 | 3.14 | 6.43 | 254 | 39.5 | 8000 | 9940 | 2547 | 3166 |
| $B_{20}$ | | 2.04 | 2.00 | 3.14 | 6.40 | 252 | 39.4 | 11500 | 11680 | 3661 | 3720 |
| | | 2.05 | 2.00 | 3.14 | 6.43 | 255 | 39.7 | 11610 | 11610 | 3700 | 3700 |
| Avr. | | | | | | | | 10370 | 11077 | 3303 | 3529 |
| | | 2.08 | 2.00 | 3.14 | 6.53 | 244 | 37.4 | 6200 | 6860 | 1973 | 2184 |
| $C_{20}$ | | 2.05 | 2.02 | 3.21 | 6.58 | 257 | 39.1 | 9000 | 9260 | 2810 | 2884 |
| | | 2.02 | 2.02 | 3.21 | 6.48 | 255 | 39.3 | 8500 | 8800 | 2647 | 2740 |
| Avr. | | | | | | | | 7900 | 8307 | 2477 | 2607 |
| | | 2.10 | 2.00 | 3.14 | 6.59 | 257 | 39.0 | 7000 | 7100 | 2228 | 2260 |
| $A_{30}$ | | 2.04 | 1.98 | 3.08 | 6.28 | 239 | 38.1 | 10100 | 10470 | 3279 | 3398 |
| | | 2.07 | 2.04 | 3.27 | 6.77 | 258 | 38.1 | 7260 | 7260 | 2220 | 2220 |
| Avr. | | | | | | | | 8120 | 8277 | 2576 | 2626 |
| | | 2.07 | 2.00 | 3.14 | 6.50 | 244 | 37.6 | 5500 | 5760 | 1751 | 1834 |
| $B_{30}$ | | 2.07 | 2.04 | 3.27 | 6.77 | 257 | 38.0 | 8740 | 8740 | 2673 | 2672 |
| | | 2.06 | 2.00 | 3.14 | 6.47 | 244 | 37.7 | 10260 | 10260 | 3268 | 3268 |
| Avr. | | | | | | | | 8166 | 8253 | 2564 | 2591 |
| | | 2.06 | 2.00 | 3.14 | 6.47 | 256 | 39.6 | 6400 | 6400 | 2039 | 2039 |
| $C_{30}$ | | 2.04 | 2.00 | 3.14 | 6.41 | 252 | 39.3 | 8470 | 8970 | 2857 | 2857 |
| | | 2.05 | 2.00 | 3.14 | 6.43 | 251 | 39.1 | 6740 | 6740 | 2130 | 2144 |
| Avr. | | | | | | | | 7203 | 7370 | 2345 | 2347 |
| | | 2.05 | 1.98 | 3.08 | 6.31 | 239 | 37.9 | 6120 | 6260 | 1987 | 2032 |
| $A_{40}$ | | 2.10 | 2.00 | 3.14 | 6.59 | 253 | 38.4 | 9290 | 9340 | 2957 | 2975 |
| | | 2.08 | 2.00 | 3.14 | 6.53 | 240 | 36.8 | 8425 | 8425 | 2681 | 2680 |
| Avr. | | | | | | | | 7945 | 8008 | 2542 | 2562 |
| | | 2.10 | 2.00 | 3.14 | 6.59 | 252 | 38.2 | 5980 | 5980 | 1904 | 1904 |
| $D_{40}$ | | 2.10 | 2.00 | 3.14 | 6.59 | 246 | 37.4 | 5870 | 5870 | 1870 | 1870 |
| | | 2.10 | 2.00 | 3.14 | 6.59 | 252 | 38.2 | 7000 | 7100 | 2230 | 2260 |
| Avr. | | | | | | | | 6283 | 6317 | 2001 | 2011 |
| | | 2.08 | 2.00 | 3.14 | 6.53 | 251 | 38.5 | 6000 | 6430 | 1910 | 2047 |
| $C_{40}$ | | 2.10 | 2.00 | 3.14 | 6.59 | 249 | 37.8 | 4480 | 4480 | 1428 | 1428 |
| | | 2.11 | 2.00 | 3.14 | 6.62 | 250 | 37.8 | 7170 | 7170 | 2282 | 2282 |
| Avr. | | | | | | | | 5883 | 6027 | 1873 | 1919 |
| Average of Averages | | | | | | | | | | | |
| A - B & C | | | | | | | | | | 3860 | 4050 |
| $A_{10}$ - $B_{10}$ & $C_{10}$ | | | | | | | | | | 3863 | 3876 |
| $A_{20}$ - $B_{20}$ & $C_{20}$ | | | | | | | | | | 3104 | 3401 |
| $A_{30}$ - $B_{30}$ & $C_{30}$ | | | | | | | | | | 2495 | 2521 |
| $A_{40}$ - $B_{40}$ & $C_{40}$ | | | | | | | | | | 2139 | 2164 |
| Average of Highest Breaks | | | | | | | | | | | |
| A - B & C | | | | | | | | | | 4529 | 4703 |
| $A_{10}$ - $B_{10}$ & $C_{10}$ | | | | | | | | | | 4468 | 4435 |
| $A_{20}$ - $B_{20}$ & $C_{20}$ | | | | | | | | | | 3526 | 3641 |
| $A_{30}$ - $B_{30}$ & $C_{30}$ | | | | | | | | | | 9404 | 3174 |
| $A_{40}$ - $B_{40}$ & $C_{40}$ | | | | | | | | | | 2490 | 2506 |

## TIME OF SET AND NORMAL CONSISTENCY

| | Time of Set By Vicat. | | | | N'rm'l C'nsistency | |
|---|---|---|---|---|---|---|
| | Initial | | Final | | | |
| | Hours | Minutes | Hours | Minutes | Neat paste Per Cent | 1:3 Sand Mortar Per Cent |
| A | 2 | 50 | 5 | 20 | 22 | 10.2 |
| $A_{10}$ | 0 | 20 | 5 | 10 | 26 | 10.8 |
| $A_{20}$ | 1 | 35 | 5 | 30 | 23 | 10.3 |
| $A_{30}$ | 4 | 40 | 8 | 30 | 22½ | 10.25 |
| $A_{40}$ | 5 | 03 | 6 | 23 | 21½ | 10.1 |
| B | 4 | 55 | 9 | 00 | 21 | 10.1 |
| $B_{10}$ | 3 | 15 | 6 | 20 | 24 | 10.5 |
| $B_{20}$ | 2 | 15 | 5 | 50 | 22½ | 10.25 |
| $B_{30}$ | 5 | 45 | 9 | 35 | 22 | 10.2 |
| $B_{40}$ | 7 | 35 | 10 | 15 | 21 | 9.9 |
| C | 3 | 50 | 5 | 55 | 21½ | 10.1 |
| $C_{10}$ | 3 | 45 | 6 | — | 25 | 10.7 |
| $C_{20}$ | 4 | 35 | 8 | 10 | 23½ | 10.4 |
| $C_{30}$ | 5 | 02 | 7 | 25 | 22½ | 10.25 |
| $C_{40}$ | 4 | 55 | 7 | 25 | 21½ | 10.1 |
| Averages | | | | | | |
| A, B, C | 3 | 52 | 6 | 45 | 21½ | 10.13 |
| $A_{10}$, $B_{10}$, $C_{10}$ | 2 | 27 | 5 | 50 | 25 | 10.66 |
| $A_{20}$, $B_{20}$, $C_{20}$ | 2 | 48 | 6 | 30 | 23 | 10.32 |
| $A_{30}$, $B_{30}$, $C_{30}$ | 5 | 09 | 8 | 30 | 22⅓ | 10.23 |
| $A_{40}$, $B_{40}$, $C_{40}$ | 5 | 51 | 8 | 01 | 21⅓ | 10.03 |

## SIEVE ANALYSIS

| Cement Series No. | Percentages | | | | | |
|---|---|---|---|---|---|---|
| | Passing No. 200 | Retained on No. 200 | Retained on No. 150 | Retained on No. 100 | Retained on No. 65 | Retained on No. 48 | Retained on No. 35 |
| A | 78.0 | 22.0 | 15.3 | 5.6 | 0.7 | 0.1 | 0.0 |
| B | 78.2 | 21.8 | 15.9 | 6.1 | 0.75 | 0.0 | 0.0 |
| C | 77.3 | 22.7 | 16.4 | 4.6 | 0.8 | 0.3 | 0.1 |
| Sand | 17.9 | 82.1 | 55.9 | 16.4 | 5.1 | 1.8 | 0.6 |

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### GENERAL SERIES

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